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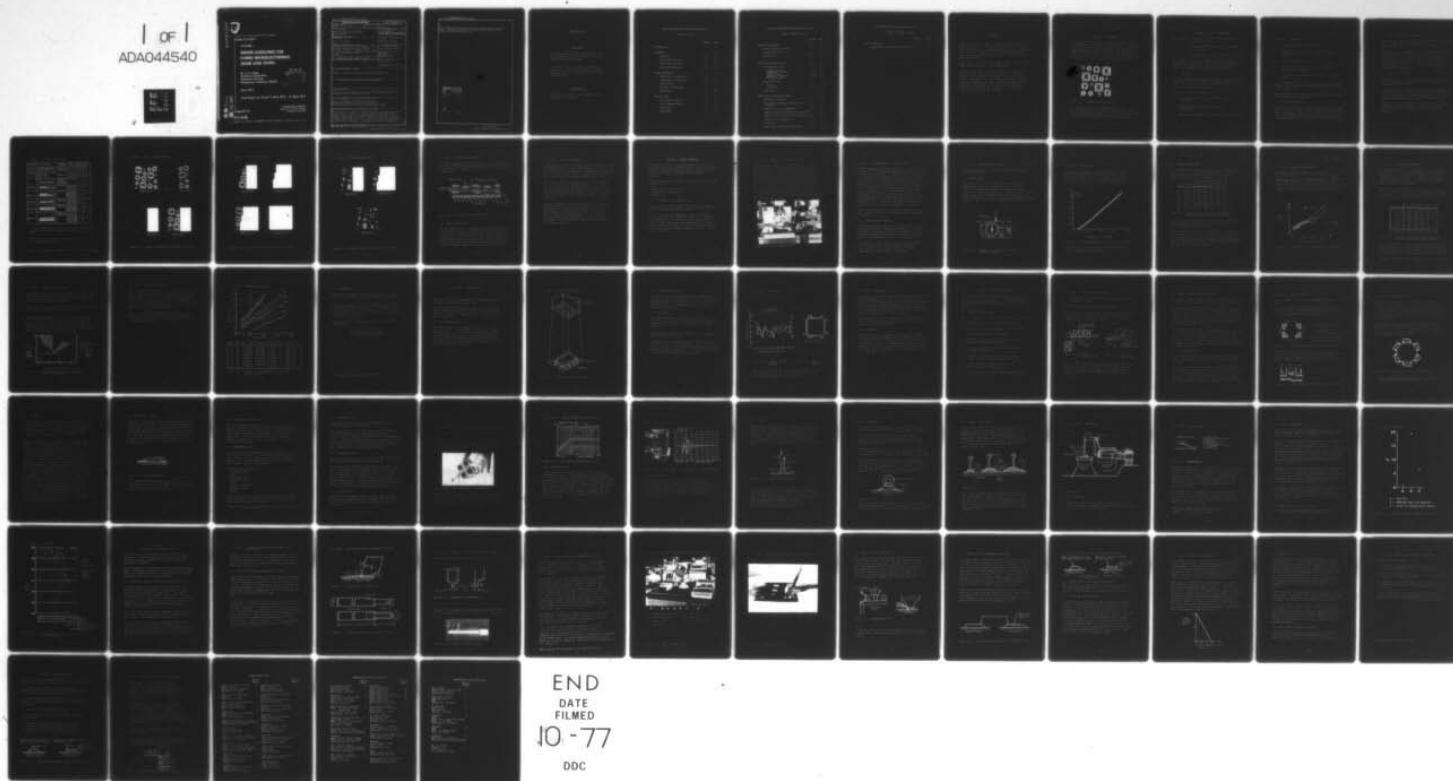
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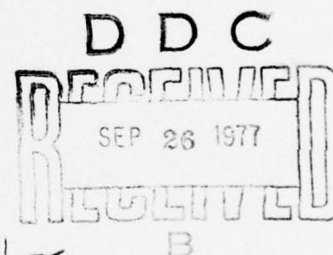
Research and Development Technical Report

ECOM-76-1358-F

VOLUME I

**DESIGN GUIDELINES FOR
HYBRID MICROELECTRONICS
(BEAM LEAD STUDY)**

Dr. J. F. Linder
Northrop Corporation
Electronics Division
Hawthorne, California 90250



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report is a study of the bonding of beam-leaded chips onto several types of hybrid substrates, mostly with thick film metallization. Beam lead semiconductors of various sizes were bonded on monolayer substrates as well as multilayer substrates of increasing complexity. The integrity of the bonding on the various types of substrates changes and permits the author to		

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draw design rules for hybrid circuits comprising beam-leaded chips. Report describes a non-destructive method to test the bonds of beam-leaded chips.

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DESIGN GUIDELINES FOR HYBRID MICROCIRCUITS

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INTRODUCTION

The objective of this contract is to define design rules for hybrid microcircuits. Little is available in the literature to draw design rules for incorporating beam leaded chips in hybrids, particularly thick film hybrids. This contract included, therefore, a study of the bonding reliability of beam-leaded chips on thick film substrates.

Furthermore, an attempt was to be made to find a non-destructive method to test the bonds of beam-leaded chips.

In this section of the report, we will review a study of the bonding of beam-leaded chips onto several types of hybrid substrates, mostly with thick film metallization. Beam lead semiconductors of various sizes were bonded on monolayer substrates as well as multilayer substrates of increasing complexity. The integrity of the bonding on the various types of substrate provides a set of rules, do's and don't's, which have been incorporated into the design rule book.

SECTION 1 SUBSTRATES

The objective of this work is to study the bonding reliability of beam-led chips onto thick film substrates. Various types of substrates were used for this study. Their overall configuration varied, but the top layout, where the chips were to be bonded, remained the same for all types. All substrates were 1.0 x 1.0 x .025 in. (25.4 x 25.4 x 0.635 mm). Figure 1.0-1 shows an enlarged scale of the universal bonding pattern layout.

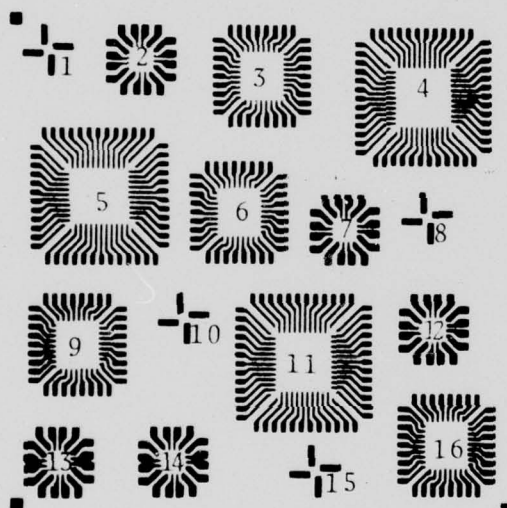


Figure 1.0-1 UNIVERSAL BONDING PATTERN

Each bonding location was assigned a number in order to permit specific identification of the chips. Positions 1, 8, 10 and 15 are bonding patterns designed to accept standard-width beams as well as the wider beams to be found on power devices.

SECTION 1 (Cont.) SUBSTRATES

The layout has: 5 positions for 16 beam chips (EIA standard)
(2, 7, 12, 13, 14);

4 positions for 34 beam chips (EIA standard)
(3, 6, 9, 16);

3 positions for 50 or 42 beam chips (4, 5, 11).

Positions 4, 5 and 11 will accommodate either 42 beam chips or 50 beam chips. The design concept (one pattern accommodating either of two chips) can be extended to include more than two chips. The concept is explained in the design guidelines.

1.1 THIN FILM

A number of plated thin film substrates were generated. Their purpose was to serve as controls. The ceramic substrate was Al_2O_3 , 99.5%, 2.0 x 2.0 x .012 in. (50.8 x 50.8 x 0.30 mm) (AlSiMag 772, from 3M Corporation).

Processing steps were as follows:

- o RF sputtering of NiCr (about 500 \AA thick, or $5 \times 10^{-5} \text{ mm}$)
- o RF sputtering of Au (about 2000 \AA thick or $2 \times 10^{-4} \text{ mm}$)
- o Application of photoresist (Shipley 1350J, a positive resist)

1.1 (Cont.) THIN FILM

- o Exposure/development of photoresist
- o Pattern plating (electrolytic) of pure Au (Sel Rex Pur-a-Gold 125 solution) to a thickness of 150 μ in. (3.8 μ m).
- o Stripping of the resist
- o Partial gold etch, to dissolve only the thin gold (where no gold was plated)
- o Nichrome etch, to eliminate NiCr where it is not protected by gold

We knew from former experience that this process gives us gold conductors very suitable for thermocompression bonding of gold wires or beams.

These substrates were, therefore, used as calibration substrates for bond quality, and named Type 0.

1.2 THICK FILM, MONOLAYER

The object of the monolayer thick film substrates was to compare with, as well as to create a base to compare, the multilayer thick film. The pattern of Figure 1.0-1 was made into a screen for screen printing, and three types of thick film gold paste were screened onto 96% Al_2O_3 1 x 1 x .025 in. (25.4 x 25.4 x 0.63 mm).

1.2 (Cont.) THICK FILM, MONOLAYER

Type 1 was done with fritless gold (Thick Film Systems, Type 4007).
Type 2 was done with low-frit gold (TFS, Type 3011).
Type 3 was done with high-frit gold (TFS, Type 3009).

One additional monolayer thick film type was generated but with a different process: low frit gold paste (TFS 3011) was screened uniformly over a 1 x 1 in. (2.54 x 2.54 cm) solid square on every substrate of this group. Photoresist was then applied to the substrates and the gold etched so as to leave only the pattern shown on Figure 1.0-1. This type of etched thick film substrate was designated Type 4.

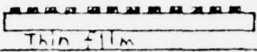

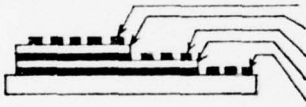
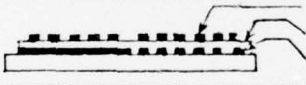
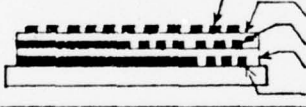
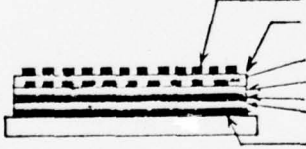
1.3 THICK FILM, MULTILAYER

In order to create a variety of multilayer "situations", five types of multilayer thick film substrates were generated, they are numbered Types 5 through 9.

Although, in these test substrates, no electrical connections exist between metal layers, additional firing cycles were introduced. This was done to simulate the firing cycles which would be done in actual production to create interconnecting vias.

Figure 1.3-1 shows sectional views of all the various substrate configurations and calls out the artworks used. Figure 1.3-2, 1.3-3 and 1.3-4 show the artworks that are called out in Figure 1.3-1.

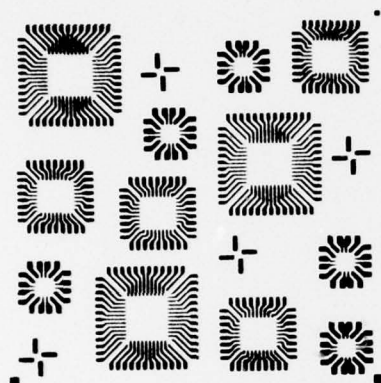
1.3 (Cont.) THICK FILM, MULTILAYER

SUBSTRATE PART NUMBER	DESCRIPTION	ARTWORK NUMBERS	THICK FILM INK TYPE	Number of Printing Oper.	Number of Firing Oper.	Type No.
88710466-1	 Thin Film	MP88710466-1	N/A	N/A	N/A	0
88710467-1	Fritless Gold (Printed Pattern)		TFS 4007	2	1	1
-2	Low frit Gold	MP88710466-1	TFS 3011	2	1	2
-3	Hi frit Gold		TFS 3009	2	1	3
-4	Low frit Gold (Etched Pattern)	MP88710467-7 (Print Solid Plane) MP88710466-1 (Etch Pattern)	TFS 3011	1	1	4
88710467-5		MP88710467-1 -2 -3	TFS 3011 ESL 4608 TFS 3011	3	4	5
88710467-6		MP88710467-1 -2 -4 -5 -6	TFS 3011 ESL 4608 TFS 3011 ESL 4608 TFS 3011	5	7	6
88710467-7		MP88710466-1 MP88710467-7 -8	TFS 3011 ESL 4608 TFS 3009	4	4	7
88710467-8		MP88710466-1 MP88710467-7 -8 -7 -9	TFS 3011 ESL 4608 TFS 3009 ESL 4608 TFS 3009	6	7	8
88710467-9		MP88710466-1 MP88710467-7 -10 -7 -7 -7 -7	TFS 3011 ESL 4608 TFS 3009 ESL 4608 TFS 3009 ESL 4608 TFS 3009	8	10	9

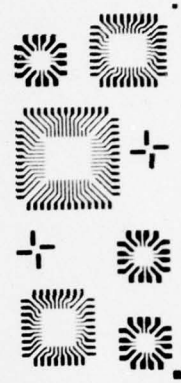
- o In cross-section sketches, dark areas represent metallization layers (planes and lines); light areas represent dielectric layers.
- o Additional firing operations required to simulate firing of via-fill metallization.

Figure 1.3-1 SUBSTRATE DEFINITION FOR BEAM LEAD BONDING DEVELOPMENT

1.3 (Cont.) THICK FILM, MULTILAYER



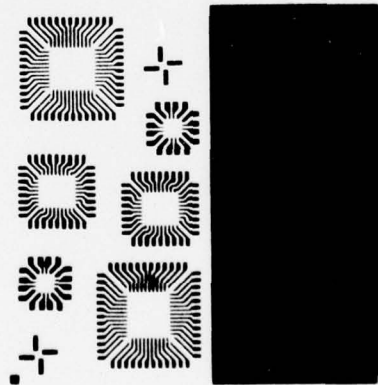
MP88710466-1



MP88710467-1



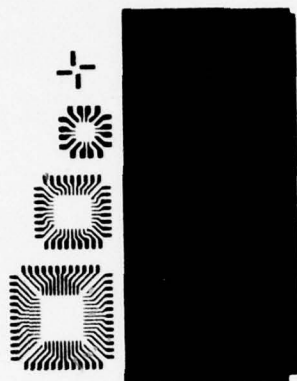
MP88710467-2



MP88710467-3

Figure 1.3-2 ARTWORK PATTERNS USED FOR PRODUCING SUBSTRATES

1.3 (Cont.) THICK FILM, MULTILAYER



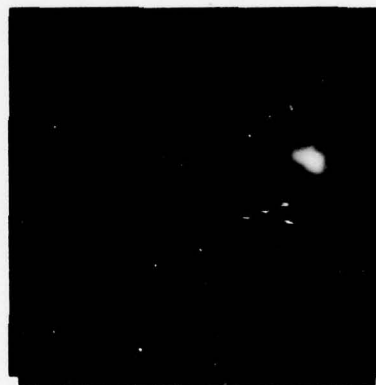
MP88710467-4



MP88710467-5



MP88710467-6



MP88710467-7

Figure 1.3-3 ARTWORK PATTERNS USED FOR PRODUCING SUBSTRATES

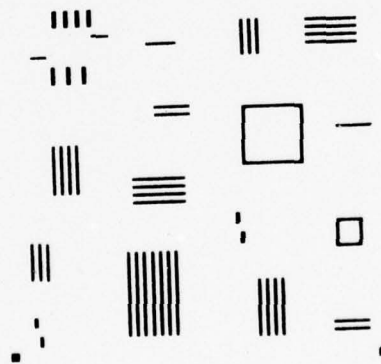
1.3 (Cont.) THICK FILM, MULTILAYER



MP88710467-8



MP88710467-9



MP88710467-10

Figure 1.3-4 ARTWORK PATTERNS USED FOR PRODUCING SUBSTRATES

1.3 (Cont.) THICK FILM, MULTILAYER

The various configurations were designed to create a multitude of relationships between the bonding pads and other metallization layers below. An example of such a relationship is illustrated in Figure 1.3-5.

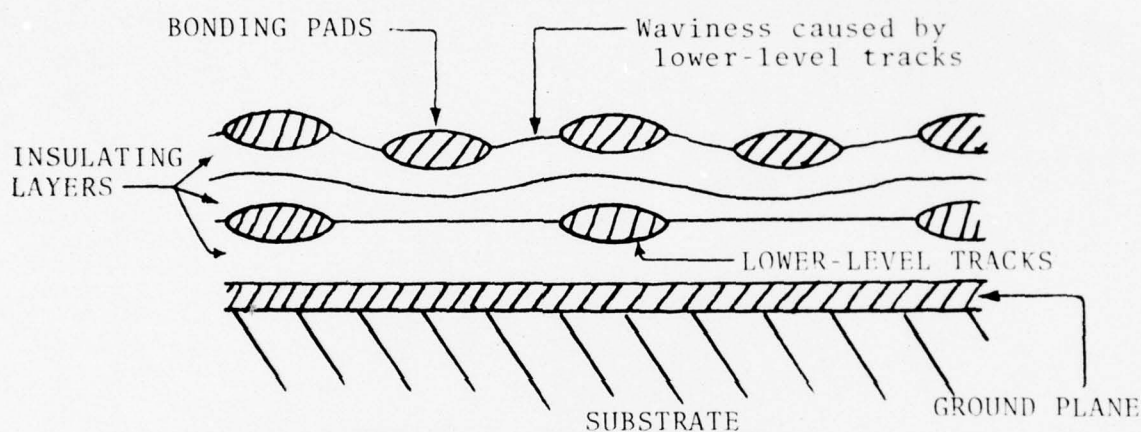


Figure 1.3-5 MULTILAYER THICK FILM SUBSTRATE

1.4 THICK FILM MATERIALS

We have had three years of experience with the materials chosen for this study. Most are from Thick Film Systems Corporation. Type 4007 was used for the fritless gold, 3011 for the low-frit gold and 3009 for the hi-frit gold. Many can be fired with one common furnace temperature profile, thus saving a considerable amount of time. No. 3009 (the gold conductor) has good adhesion to the 96% alumina substrate as well as to the glass-ceramic

1.4 (Cont.) THICK FILM MATERIALS

insulation layers. Due to its high glass-frit content, it is not recommended for pads or layers where bonding is to be done. The No. 3011 (low frit gold conductor) has good adhesion on alumina or glass-ceramics, while offering a good bondability for both ultrasonic Al bonding and thermocompression gold bonding.

Type 4007 is a no-frit gold conductor paste. It is used in cases where no frit is tolerable, and has a small percentage of CuO or similar oxide, for adhesion to the alumina. It requires a firing temperature 150°C higher than 3009 or 3011. The insulating glass ESL 4608 CFB-M2 is a paste of a recrystallizing glass-ceramic, manufactured by Electro-Science Laboratories, Inc.

For these multilayers, the gold paste chosen was TFS 3011 for any layer where bonding was to be done, and TFS 3009 for the intermediate gold conductor layers. The insulator glass between metal layers was ESL 4608-CFB-M2. Each insulating layer was double screened and double fired, in order to simulate actual production processing. (In actual production, such double screening and firing greatly reduces pin holes in the insulator material.)

SECTION 2 BONDING PARAMETERS

This chapter describes the bonding parameters, that is the conditions under which the wobble bonder performs its operations. It gives the domain of bonding parameters we have explored, as well as the range of parameters giving reliable bonding.

The three important parameters of all thermocompression bonding operations are:

- Temperature of the bonding tool.
- Temperature of the substrate.
- Bonding force.

2.1 TEMPERATURE OF THE BONDING TOOL

Previous experience has shown that the interface temperature during thermocompression bonding should be at least 315°C

One of the factors determining the interface temperature is the temperature of the bonding tool (or quill). Generally, the temperature of the tool will be chosen higher than the interface temperature, while the temperature of the substrate will be held a little lower, in order to submit the already bonded chips and other mounted components to as low a temperature as possible.

2.1 (Cont.) TEMPERATURE OF THE BONDING TOOL

The bonding tool of the K&S 576 wobble bonder is heated by a little coil heater wrapped around the tool very near the Tungsten Carbide or Titanium Carbide tip. The machine has a meter indicating the current flowing through the heater. This proved, however, not to be a reliable indication of the tool temperature. During the bonding cycle, the tool reaches a maximum temperature just before chip pickup, but as soon as the suction of air (maintaining the chip in the tool) takes place, the temperature of the tool may drop by 200°C , to a temperature too low for a reliable bond. It is therefore important to monitor the temperature of the bonding tool throughout the bonding cycle. We did this with the installation illustrated on Figure 2.1-1.

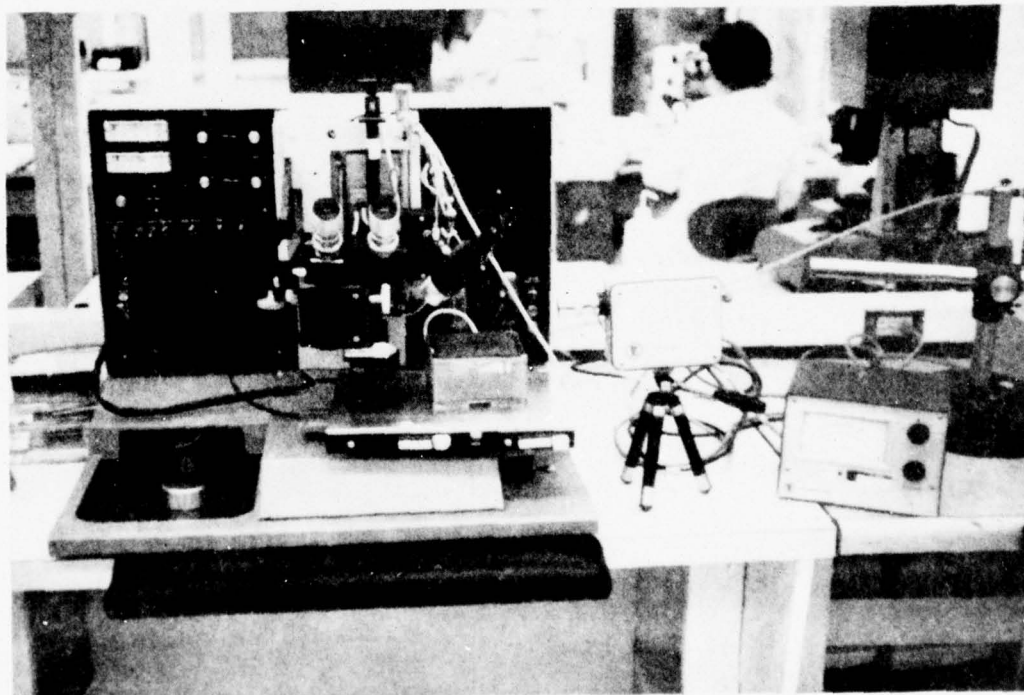


Figure 2.1-1 K&S 576 WOBBLE BONDER

2.1 (Cont.) TEMPERATURE OF THE BONDING TOOL

A Barnes Engineering Infrascopes (Mark I) is aimed at the tip of the tool. Its 0.7° pickup angle insures that only the tool tip is viewed by the bolometer. A direct readout meter with four (4) scales gives the temperature of the tool tip at all times. It allows for easy adjustment of the heater current and the pickup vacuum so as to achieve the desired temperature of the tool tip at the time of the bonding. If such an instrument is not available, then a fine thermocouple should be used, with .001 inch to .002 inch (25 to 50 μm) diameter wire. This thermocouple should be brazed or spot welded to the side of the bonding tool tip. The temperature should then be measured through one complete cycle of pick-up and bonding with actual pick-up of a die. Vacuum and heater current could then be adjusted to give the right tool temperature at bonding.

For our investigation, we varied the tool temperature between 300°C and 400°C so as to see in what interval reliable bonds are obtained.

2.2 TEMPERATURE OF SUBSTRATE

The temperature of the substrate is actually the main factor defining the interface temperature at bonding. It is easier to measure and control than the tool temperature because the substrate is mounted onto a hot plate, which has cartridge heaters, a thermocouple and a thermostatic control.

The temperature of this hot plate is held to the indicated value $\pm 10^\circ\text{C}$ or better. And the surface temperature of the substrate is only about 10°C lower. This was established by a thermocouple on the substrate.

2.2 (Cont.) TEMPERATURE OF SUBSTRATE

For our investigation, we varied the substrate temperature from 100°C to 425°C.

2.3 BONDING FORCE

The bonding force, for a defined set of tool and substrate temperatures, defines the squashout factor of the bonded beams. In the K&S wobble-bonder, the bonding force can be varied by varying the tension of a spring on top of the bonding head. It has a dial indicator with only an arbitrary scale and must be calibrated. To do that, we used a Dillon compression gauge (10 lbs = 42 N full scale), as illustrated on Figure 2.3-1.

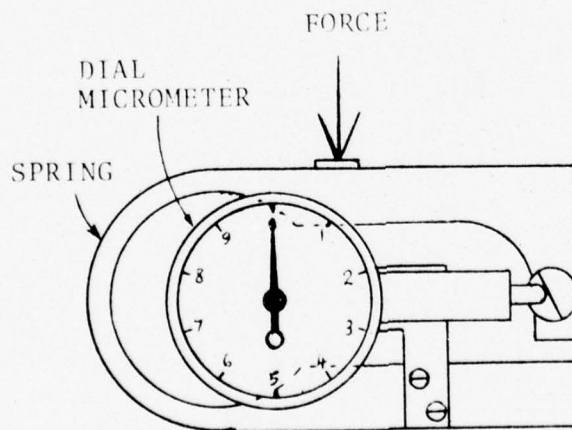


Figure 2.3-1 COMPRESSION GAUGE USED TO CALIBRATE BONDING FORCE SCALE

2.3 (Cont.) BONDING FORCE

We measured the bonding force and compared the dial indication several times during the program, and we found this force-versus-dial reading to be very consistent. Illustrated on Figure 2.3-2 is the force-versus-dial reading function for our bonder. As one can see, the curve is almost linear.

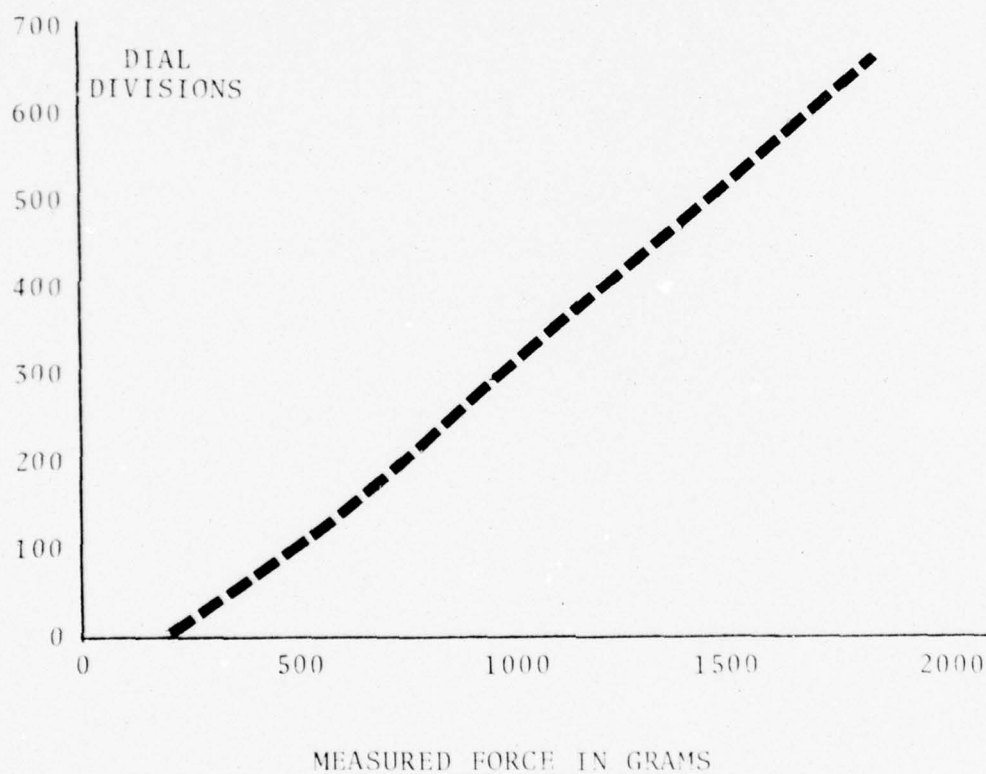


Figure 2.3-2 MEASURED BONDING FORCE VERSUS INDICATOR READING

Four-beam chips were then bonded on thin film substrates in order to compare bonding variables.

2.4 PARAMETER COMBINATIONS

We first varied tool temperature and pressure according to the grid of Table 2.4-1, while keeping the substrate at a constant temperature of 300°C, then measured the resultant squashout factor. (Squashout factor is explained in Section 4.)

TOOL TEMP.	BONDING FORCE IN GRAMS				
	200	400	600	800	1000
300°C	1.22	1.29	1.51	1.60	1.67
325°C	1.25	1.39	1.48	1.59	1.65
350°C	1.21	1.30	1.47	1.57	1.65
375°C	1.20	1.30	1.41	1.53	1.67
400°C	1.21	1.29	1.44	1.56	1.67
Average	1.22	1.31	1.46	1.57	1.66

Table 2.4-1 SQUASHOUT FACTOR VERSUS BONDING PARAMETERS
FOR 4-BEAM CHIPS ON THIN FILM SUBSTRATES

As can be seen, the squashout factor does not have a definite dependence upon the tool temperature (in the range tested), but is very dependent on the force applied.

All the chips used for this grid were pulled to destruction and no bond failure (failure type E in Figure 5.3-1) was detected. This indicates that the limits of reliable bonding parameters were outside this grid and that, by taking our bonding parameters near the middle of the grid, we would be far enough away from the limits to have reliable bonding.

2.4 (Cont.) PARAMETER COMBINATIONS

We wanted to be in the middle of the squashout range, near $\frac{1.1 + 1.6}{2} = 1.35$. We chose the point: tool temperature, 350°C, and : bonding force 400 g as being the closest (for 4-beam chips on thin film substrates). With these two parameters fixed, we then varied the substrate temperature between 100°C and 425°C. We found a dependence between substrate temperature and squashout factor as shown in Figure 2.4-1.

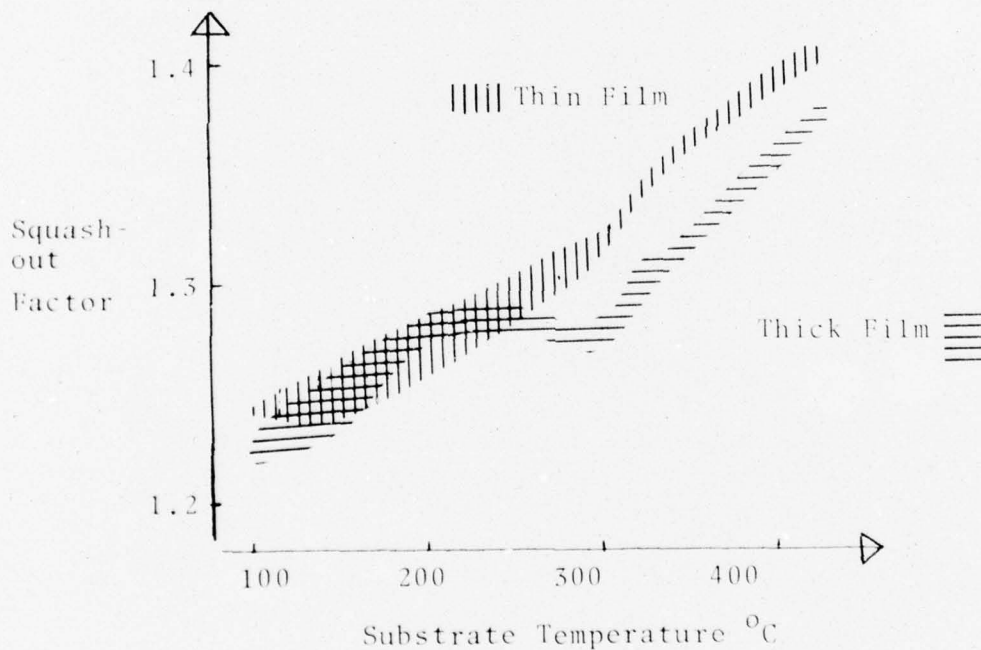


Figure 2.4-1 SQUASHOUT FACTOR VERSUS SUBSTRATE TEMPERATURE

2.4 (Cont.) PARAMETER COMBINATIONS

The bonds from Figure 2.4-1 were then tested with an INDEPT*, at 15 g force. No failure was observed, even with a substrate temperature as low as 100°C. This confirmed the fact that a substrate temperature of 300°C is adequate, while giving us the right amount of squashout (with 350°C tool temperature and 400 g force for 4-beam chips).

With 4-beam chips, on thick film gold, (low frit, substrate type 2) we ran the same grid of tool temperature versus pressure as in Table 2.4.1. We kept the substrate temperature at 300°C and measured the squashout factor (see Table 2.4-2).

TOOL TEMP.	BONDING FORCE IN GRAMS				
	200	400	600	800	1000
300°C	1.26	1.27	1.51	1.62	1.59
325°C	1.22	1.29	1.43	1.59	1.68
350°C	1.23	1.31	1.40	1.45	1.71
375°C	1.25	1.31	1.41	1.43	1.72
400°C	1.22	1.30	1.42	1.50	1.81
Average	1.24	1.30	1.43	1.52	1.70

Table 2.4-2 SQUASHOUT FACTOR VERSUS BONDING PARAMETERS FOR 4-BEAM CHIPS ON THICK FILM SUBSTRATES

Here, again, there is no clear dependence between squashout and tool temperature, except perhaps at the highest force. We performed a destructive pull test on these chips and the only bond failures observed were a couple of sporadic failures at 375°C.

* INDEPT is Individual Non-Destructive Push Test (see Section 6).

2.4 (Cont.) PARAMETER COMBINATIONS

The extreme parameters of either end of the grid, however, showed no indication of unreliable bonding. Therefore, the same combination of parameters (350°C tool, 400 g pressure) was used for 4-beam chips on thick film as on thin film.

We then compared squashout to substrate temperature for the thick film substrates. The results are in Figure 2.4-1.

We then performed destructive pull tests. The results showed that the substrate temperature has a drastic influence on the bonding reliability of chips bonded on thick film. These results are shown in Figure 2.4-2. For example, at 200°C substrate temperature, we will have between 50% and 100% bond failures and the force at rupture will be about 16 grams.

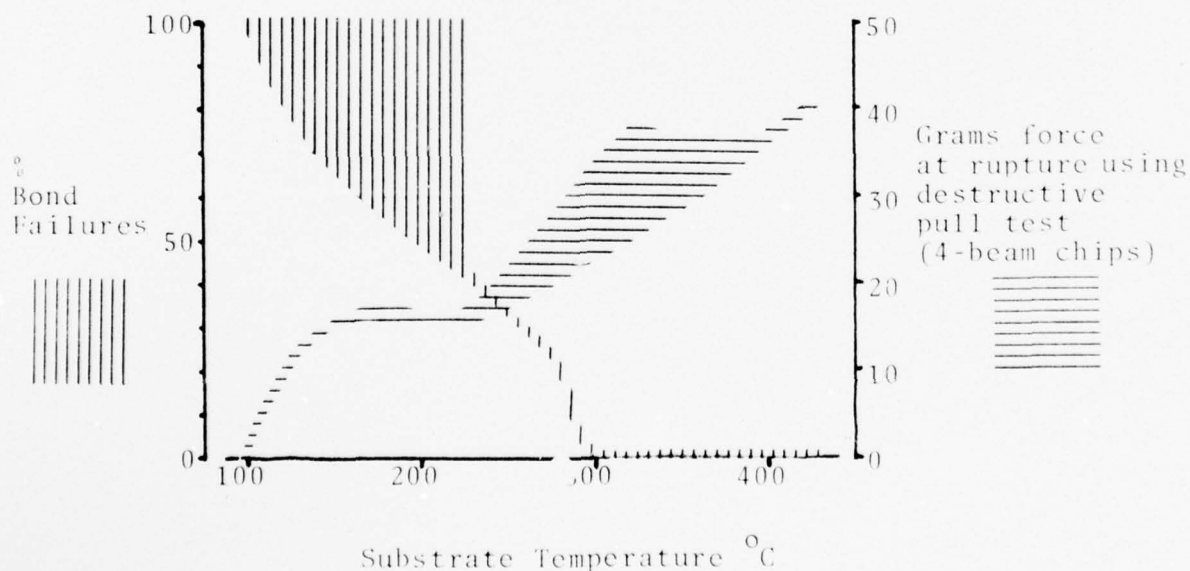


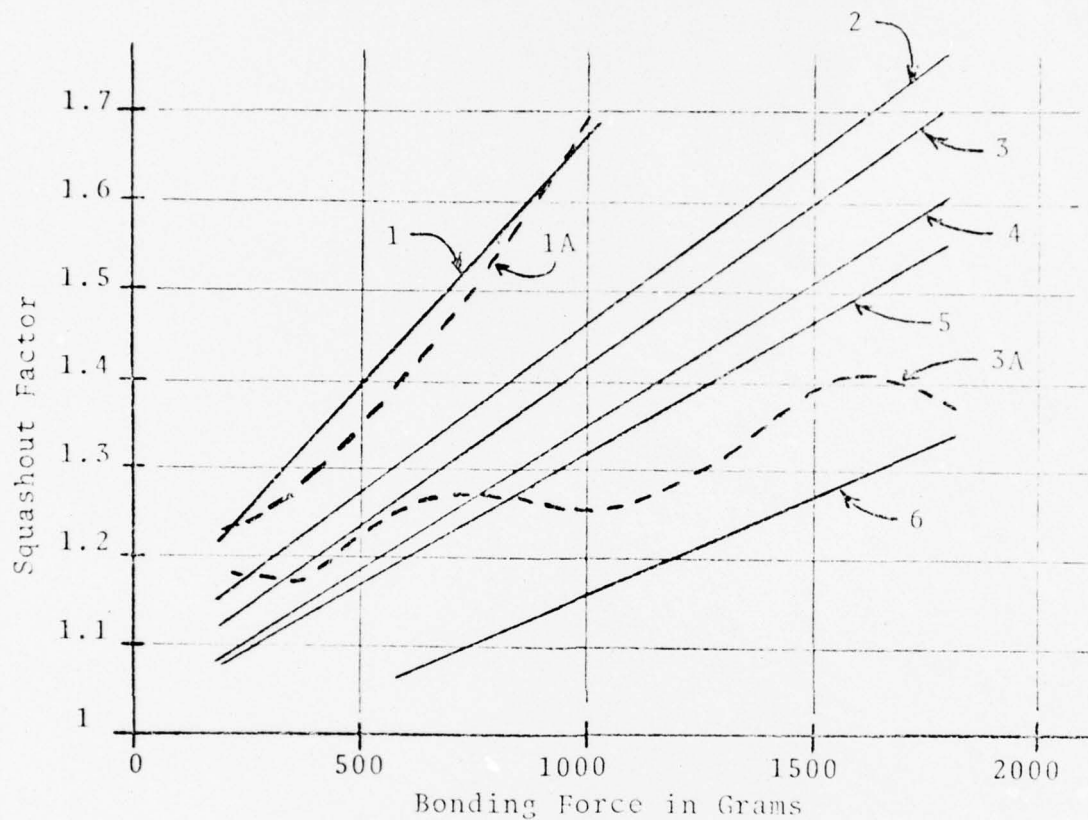
Figure 2.4-2 BONDING RELIABILITY VERSUS TEMPERATURE OF THICK FILM SUBSTRATE

2.4 (Cont.) PARAMETER COMBINATIONS

Having established the bonding force needed for a four-beam chip, we next performed bonding force experiments to determine the forces required to achieve a certain squashout on chips having various numbers of beams. We used various tool shapes, but limited our investigation largely to thin film substrates as we found the squashout difficult to measure on thick film and varying erratically (curve 3A on Figure 2.4-3).

Figure 2.4-3 shows the squashout factor in function of the bonding force for various chips. We used these curves to determine the force needed at bonding to maintain the average squashout between 1.2 and 1.4.

2.4 (Cont.) PARAMETER COMBINATIONS



CURVE #	CHIP TYPE	CHIP MFG.	TOOL TYPE	SUBSTRATE MAT'L.
1	4 BEAM	MOTOROLA	FLAT	THIN FILM
1A	4 BEAM	MOTOROLA	FLAT	THICK FILM
2	16 BEAM	MOTOROLA	FLAT	THIN FILM
3	16 BEAM	MOTOROLA	CONVEX	THIN FILM
3A	16 BEAM	MOTOROLA	CONVEX	THICK FILM
4	33 BEAM	MOTOROLA	FLAT	THIN FILM
5	33 BEAM	MOTOROLA	CONVEX	THIN FILM
6	42 BEAM	T.I.	CONVEX	THIN FILM

Figure 2.4-3 SQUASHOUT FACTOR VERSUS BONDING FORCE FOR VARIOUS SIZE CHIPS

2.5 CONCLUSIONS

The results illustrated on Figure 2.4-2 brought us to increase the substrate temperature to 320°C for bonding on thick film.

For the larger chips, we kept the tool temperature at 350°C* as well as the substrate temperature of 300°C for thin film and 320°C for thick film. We established the force to be applied by measuring the squashout versus pressure for the various types of chips: see Figure 2.4-3.

As a result of this information, we adopted the following bonding forces:

for 16-beam chips: 600 grams
for 33-beam chips: 1000 grams
for 42-beam chips: 1400 grams

* measured less than a second before bonding.

SECTION 3 BONDING TOOLS

The shape of a Beam-Lead Bonding Tool in relationship with the chip is illustrated on Figure 3.1-1.

Upon bonding, the heated tool comes down with the chip on the proper location on the substrate, and by a precession motion (wobble) accompanied by pressure, squashes and bonds the beams one after the other.

3.1 FLAT BONDING SURFACES

The bonding surface, as represented on Figure 3.1-1 is flat. This type of tool is used commonly for small chips. In this program, we used flat tools for the 4-beam and 16 beam chips. For larger chips, the variation of distance between bonding edge and tool axis during the wobble motion becomes too large. The corner beams, upon bonding, become squashed much more than the ones in the middle of the sides.

3.1 (Cont.) FLAT BONDING SURFACES

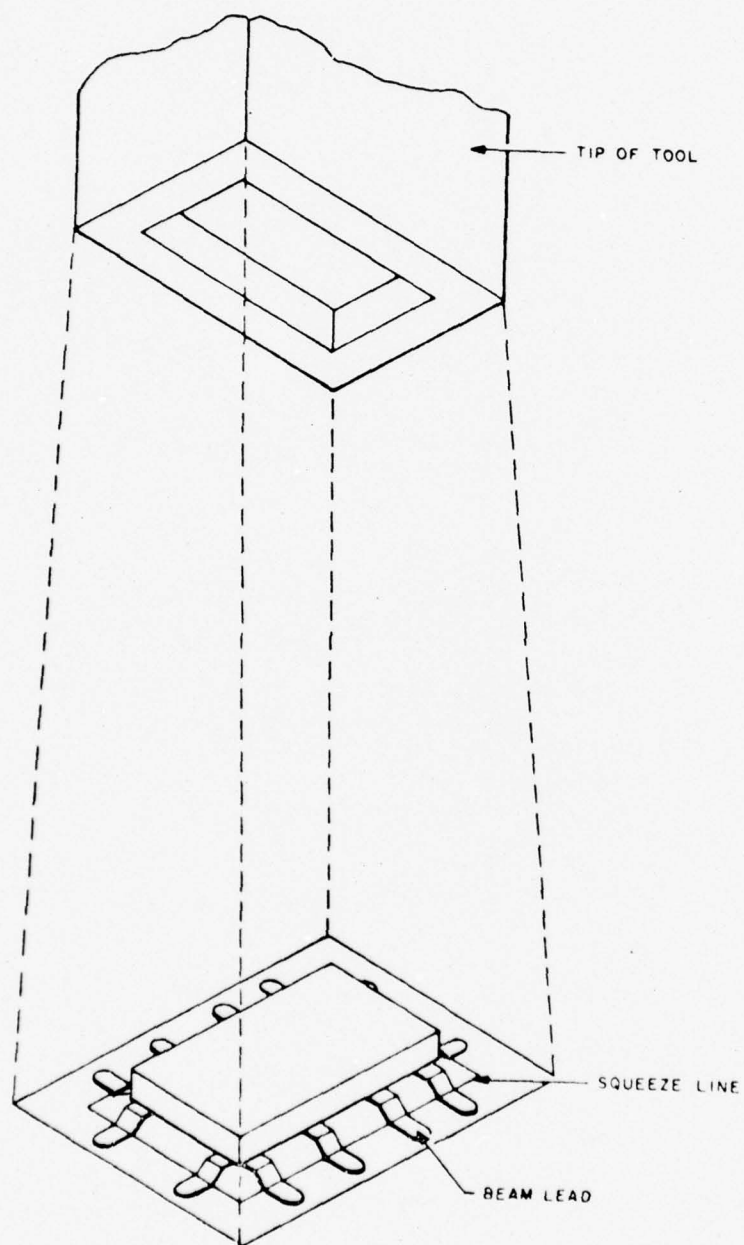


Figure 3.1-1 BONDING TOOL/BEAM LEADED CHIP

3.2 CONVEX BONDING SURFACES

The way to render the squashout more uniform around a large, beam-leaded chip is to use a convex-faced tool. This ensures, among other things, that the portion of the tool surface doing the bonding (that is: exerting the pressure) at any time is parallel to the substrate.

3.3 CONCLUSIONS

We compared the bonding results of flat and convex tools for the 16 beam chips and for the 33 beam chips. The average squashout (see Figure 3.3-1) turned out to be less with the convex tools.

Then we compared the individual squashout of the individual beams around a 33-beam chip.

An example of the individual beam data is shown in Figure 3.3-1. Figure 3.3-2 defines the beam numbering sequence called out in Figure 3.3-1. For Figure 3.3-1, the bonding parameters employed during the bonding operations were: tool temp 350°C, substrate temperature 300°C, bonding force 1,000 grams.

3.3 (Cont.) CONCLUSIONS

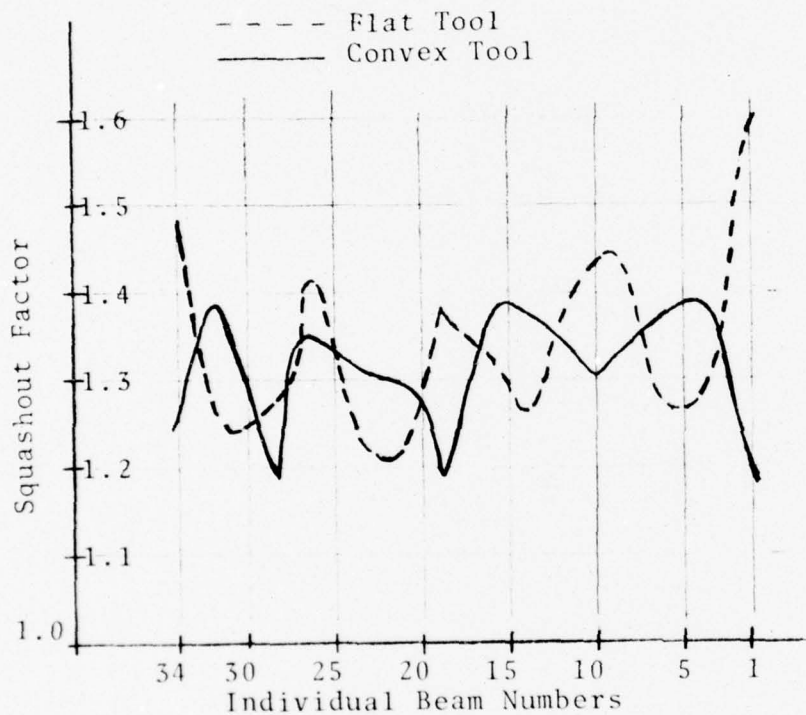


Figure 3.3-1 INDIVIDUAL BEAM SQUASHOUT FACTORS

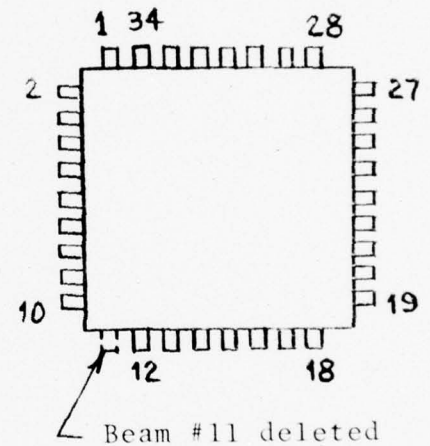


Figure 3.3-2 BEAM NUMBERING SEQUENCE

Note that for the flat tool, the corner beams squash more than the center beams; while the convex tool gives more squash to the center beams compared to the corner beams.

3.3 (Cont.) CONCLUSIONS

We conclude from these individual beam measurements that precise, uniform squashout of large chips is not feasible using the standard 1° of wobble angle built into the K&S bonding equipment. The information we received from Motorola, during our visit to Phoenix, Arizona, was that they had modified their K&S machine to $\frac{1}{2}^{\circ}$ wobble angle and have thereby achieved much more consistent squashouts on large chips (20 beams or more).

For the bonding on our test substrates, we used flat tools for the 4-beam chips and 16-beam chips, and convex tools for the 33-beam chips and the 42-beam chips.

3.4 DIMENSIONS

In order to satisfy the bonding length, distance from bond to chip and "bugging" requirements, it is recommended to design a distance of 2.5 mils (.064 mm) between tool inside edge and outside edge of the chip. In other words, once the outside dimensions (including tolerance) of the chip have been defined, one should order the bonding tool with inside dimensions .005" (.0125 cm) larger each way.

SECTION 4 INSPECTION CRITERIA

This program included visual inspections aimed mostly at the gross defects (cracks, breaks, etc.). Our main emphasis was directed toward the bonds themselves. Our goal was to verify criteria currently used in the industry or to establish new ones.

4.1 PRESENT INDUSTRY CRITERIA

Here is a typical set of inspection criteria used in the industry.

1. Bonded beams must show a definite tool impression.
2. All beams must be uniformly bonded to the substrate.
3. Beams must show no signs of cracking.
4. There must be no sharp angle created in the beam either at the bond or the chip edge.
5. No cracks or indentation in the nitride should touch the edge of the silicon.
6. Squashed width should be more than 110% but not greater than 160% of undeformed beam lead width.
7. Correct alignment. Not more than $1/3$ of the undeformed beam off bonding pad.
8. Length of bond must be 0.001 inches (25 μ m) or greater.

4.1 (Cont.) PRESENT INDUSTRY CRITERIA

9. Unbonded length must be 0.0015 in. (38 μm) or greater from edge of nitride.
10. Bugging - 0.001 to 0.003 in. (25 - 76 μm)

The most important of these factors is the squashout of the beams. After bonding, the outer portion of the beams should display a flattening and a widening called squashout, characterized by a squashout factor S (see Figure 4.1-1).

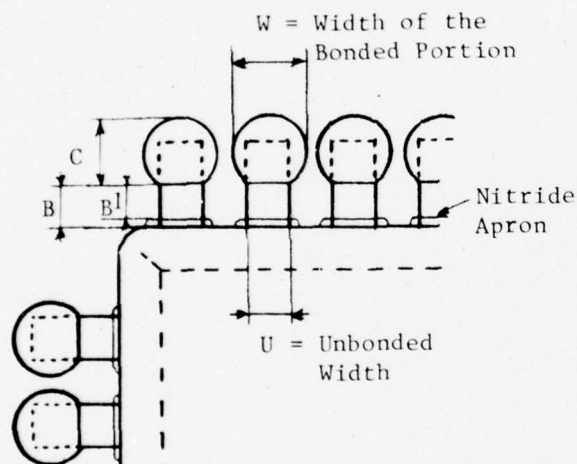


Figure 4.1-1 TOP VIEW OF BONDED BEAMS

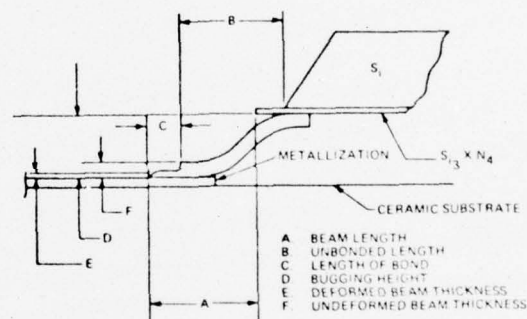


Figure 4.1-2 SIDE VIEW BONDED BEAMS

where $S = \frac{W}{U}$. Typically, we used an acceptance range for S of 1.1 to 1.6 as suggested by experts at Motorola Semiconductors. However, if a push test like INDEPT is to be applied to these beams, we recommend that the squashout range be narrowed to 1.1 to 1.4.

4.1 (Cont.) PRESENT INDUSTRY CRITERIA

In Chapter 2 (Bonding Parameters), we give the bonding parameters which will produce a squashout factor in the range recommended.

Besides the squashout, the unbonded length (letter B in Figure 4.1-1) as well as the length of the bonded portion (letter C in Figure 4.1-1) are important factors. In order to produce proper "bugging" (0.001 to 0.003 inch or .025 to .076 mm), the unbonded length B should be 0.0015 inch (.038 mm) at least from the edge of the nitride apron, or .002 inch (.050 mm) from the edge of the silicon, whichever is smaller.

Another sign detectable visually is the bugging. After bonding, a chip sees its beams assume the shape illustrated on Figure 4.1-2 and is raised above the substrate by .001 to .003 inch (.025 to .076 mm). Like for the squashout, the bugging, if observed, does not insure that the bonding has been good. But the absence of bugging (like the absence of squashout) certainly tells that no bonding has occurred.

4.2 PROGRAM ACTIVITIES

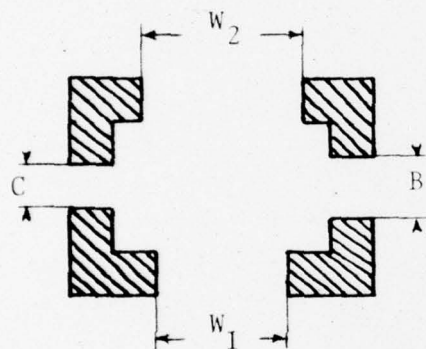
As we planned to investigate the effect of various bonding parameters (see Chapter 2), we had to perform visual measurements on the bonds.

For an inspector to measure length of a bond, unbonded length, and squashout, he must have some scale provided with his microscope. The most convenient place for this scale to be is in the eyepiece, as a reticle superimposed on the image. A common solution is a regular decimal scale enabling direct measurement of length, width, etc. To measure squashout, however, it requires

4.2 (Cont.) PROGRAM ACTIVITIES

some calculation from the inspector, namely the computation of ratios.

A simpler solution is represented by the pattern in Figure 4.2-1 (designed by Motorola) which is ideal for a go/no-go inspection of chips when all the beams are of the same width.



B = minimum unbonded length
(e.g. .0015" or .038 mm)

C = minimum bond length
(e.g. .001" or .025 mm)

W_1 = width of minimum squashout

W_2 = width of maximum squashout

Figure 4.2-1 GO/NO-GO INSPECTION TOOL FOR BEAMS OF SAME WIDTH

A program like ours involved, however, chips from different manufacturers and design, with beams of different width. Furthermore, we wanted to measure the squashout, so we developed a series of patterns, one of which is shown on Figure 4.2-2.

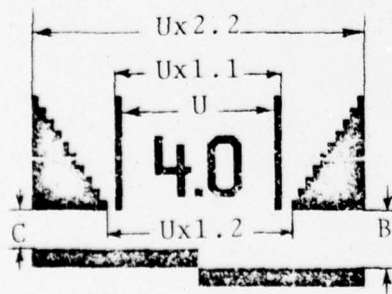


Figure 4.2-2 BASIC RETICULE PATTERN FOR MEASURING SQUASHOUT

4.2 (Cont.) PROGRAM ACTIVITIES

The patterns were generated for six (6) values of beam width from $U = 3$ mils (.075 mm) to $U = 4$ mils (.1 mm), and grouped in a circle as shown on Figure 4.2-3. The complete group was reduced to a glass copy* which, after cutting, was mounted in the eyepiece of the microscope. The final dimension of the pattern was such as to represent the exact dimensions for an object observed at 100X magnification.

Upon looking at a beam, the inspector would first turn to the pattern with U coinciding with the width of the beam. He can check B and C and, sliding the bonded portion of the beam between the two stepped scales, can read the squashout factor directly in 0.1 increments of squashout ratio.

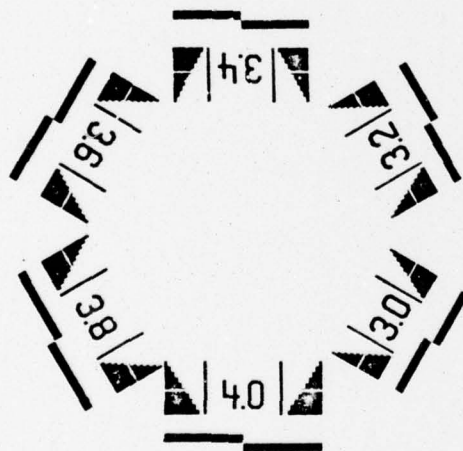


Figure 4.2-3 INSPECTION TOOL FOR SIX (6) BEAM WIDTHS

* It is recommended to create such a pattern in a transparent, colored but not too dark emulsion like a diazo, rather than on an opaque photographic emulsion.

4.3 CONCLUSIONS

As seen in Chapters 2 and 3, the squashout can vary widely with the bonding parameters, the tool type, etc. But in the series of chips we used for our investigation of the bonding parameters, we did not see any failure at INDEPT for values of squashout below 1.1 to above 1.6. We have to conclude that the range of squashout ratios from 1.1 to 1.6 is acceptable.

However, if an INDEPT is to be performed on the bonded chips, the upper limit of the squashout ratio must be brought down to about 1.4. If the squashout ratio is high, the edges of the beam meld into the bonding pad, and the push tool cannot grab the edge of the beam to perform the push test. This effect is particularly pronounced on thick film, to the point where it will be very difficult to even measure the squashout ratio if it is over 1.5. The edges of the beam "disappear", namely into the thick film conductor and become indistinguishable. An important inspection criterion when setting-up a wobble bonder, especially after each change of bonding tool, is the uniformity of the squashout around the chip. It translates into the alignment of the tool, and becomes more critical for larger chips. The K&S Model 576 wobble-bonder, which is the workhorse of the microelectronics industry, does not, alas, have a provision for alignment of the tool. One has to loosen the whole bonding head (two big allen-screws), shim its back for front-to-back deflection and move it laterally by hand for left to right deflection. It is a time-consuming and frustrating trial and error operation. We modified our K&S bonder by replacing the fixed length front stops of the tripod with a variable length stop that can be controlled by fine thread screws. It made tool alignment much faster and easier.

4.3 CONCLUSIONS (Cont.)

The other visual inspection criteria mentioned above make good common sense for whoever has any experience in bonding beam leaded chips. Particularly important is the minimum distance between the nitride apron and the heel of the bond. Not only does bonding too close to the nitride present chances to crack it and to cause subsequent failures, but bonding too close on one side means bonding too far on the other side, and the bugging of the chip will be very non-uniform, as illustrated in Figure 4.3-1.

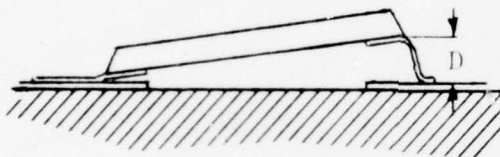


Figure 4.3-1 NON-UNIFORM BUGGING

A well-bonded chip should be fairly parallel to the substrate. A chip, where the distance D (see Figure 4.3-1) is on one side more than twice what it is on the other side, has had its beams unduly stressed and should be rejected.

5.0 BOND TESTING (TOTAL CHIP)

After having bonded the chips on the test substrates, the next step was to submit the bonds to various tests in order to determine the bond integrity. Electrical tests were proposed, but we could obtain only mechanical sample chips, so no electrical test was possible. Several environmental tests were conducted. Finally, a sample destructive pull test informed us of the type of failures encountered.

5.1 ENVIRONMENTAL TESTS

The purpose of the environmental tests is to reproduce, or preferably exceed, the stresses the bonded beam-leaded chips are likely to encounter. The tests chosen are those usually performed on hybrids. These tests were comparable, and in most cases identical, to those called for in MIL-STD-883.

Environmental tests included:

- Temperature soak
INDEPT⁴¹
- Temperature cycle
- Temperature shock
INDEPT
- Mechanical vibration
- Mechanical shock
INDEPT

A mechanical vibration and shock test was preferred over continuous acceleration (e.g. centrifuge) as being more stringent and being applied more easily to all axes.

⁴¹INDEPT is Individual Non-Destructive Push Test. (See Section 6.)

5.1.1 Temperature Soak

After all the chips were bonded, a continuous 168-hour soak at 125°C was given to the substrates.

After temperature soak, 20% of the substrates of each batch were segregated and put aside in order that they could serve as controls, while the other 80% went through the other environmental stresses. The above-mentioned batches were as follows: The single layer substrates (type 0 through 4 inclusive) were in batches of 15 (3 controls plus 12 to test) and the multilayer substrates were in batches of 30 (6 controls plus 24 to test).

5.1.2 Temperature Cycling

This test consisted of 15 cycles, in dry air, from -55°C to +125°C, per MIL-STD-883, Method 1010.1, test condition B.

The substrates were laid flat on an aluminum tray (with ½" high edges to avoid them being blown about by the fan) and placed in a Delta Design Model 8000 CD temperature chamber. This machine has two chambers, with a carriage that goes from one to the other in less than five (5) seconds. The air is circulated in each chamber by a fan. The hot chamber is heated electrically, while the cold chamber is cooled by dry liquid nitrogen. The cycling was always started and ended in the hot chamber.

5.1.3 Thermal Shock

The next test was a thermal shock according to MIL-STD-883A, Method 1011.1 Condition B (15 cycles between -55°C and 125°C). The hot liquid used was FC43; the cold liquid was FC78, cooled with dry ice.

5.1.3 (Cont.) Thermal Shock

The substrates were in Teflon or Polypropylene trays. Here again, the test was started and ended on the hot side of the chamber.

5.1.4 Mechanical Vibration

The substrates were subjected to a variable frequency vibration test from 20 to 2000 Hz at 50 G , along the three mutually perpendicular axes (per MIL-STD-883, Method 2007, Condition B). They were wax-mounted on the six faces of a steel block as shown in Figure 5.1.4-1

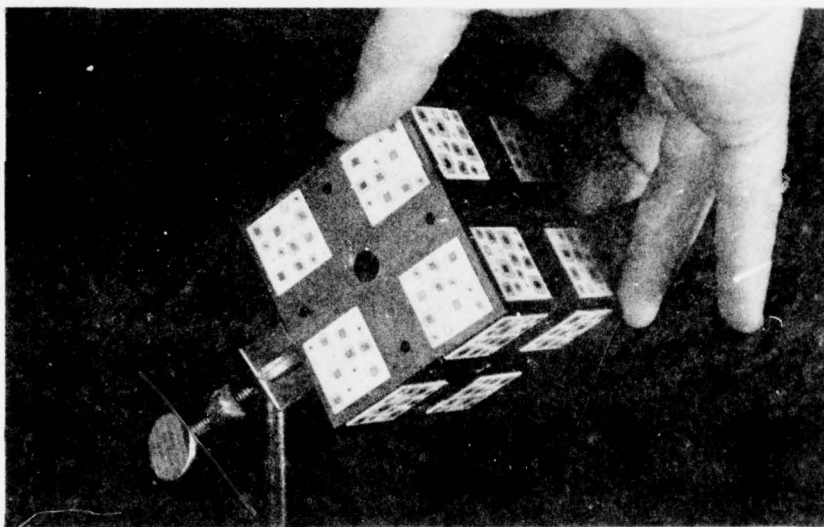


Figure 5.1.4-1 SUBSTRATES MOUNTED ON TESTING BLOCK

The block was then mounted on a computer controlled shaker table which vibrated the block with a frequency varying as a function of time. The peak acceleration as a function of the frequency is shown on the graph of the Figure 5.1.4-2. The test was repeated along each of the three axes of the cube.

5.1.4 (Cont.) SUBSTRATES MOUNTED ON TESTING BLOCK

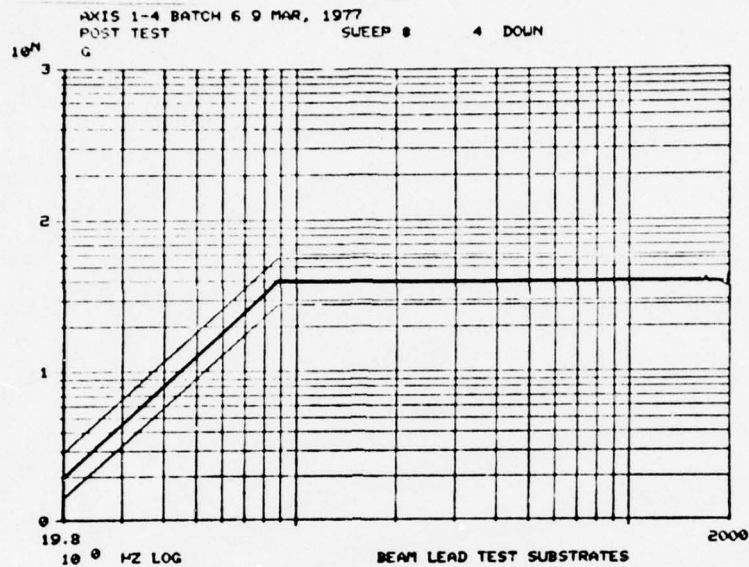


Figure 5.1.4-2 ACCELERATION VERSUS FREQUENCY GRAPH

5.1.5 Mechanical Shock

For the shock test, the cube of Figure 5.1.4-2 was mounted on the hammer of a seven (7) foot drop tower, as shown on Figure 5.1.5-1. The vertical acceleration of the hammer was increased by the addition of a "Bungee" rubber cord. A lead pellet was placed on the anvil of the drop tower, to produce a defined deceleration pulse peaking at 4000 to 5000 G. A typical deceleration versus time graph is shown on Figure 5.1.5-2. After each shock, the cube was rotated and the test repeated. Altogether, the shock test was done six (6) times for each batch, so as to have each face down one time.

5.1.5 (Cont.) Mechanical Shock

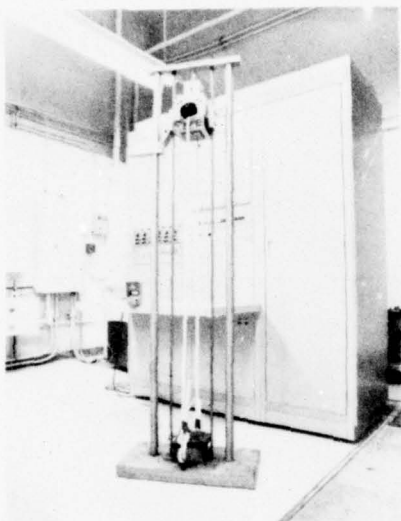


Figure 5.1.5-1 DROP TOWER

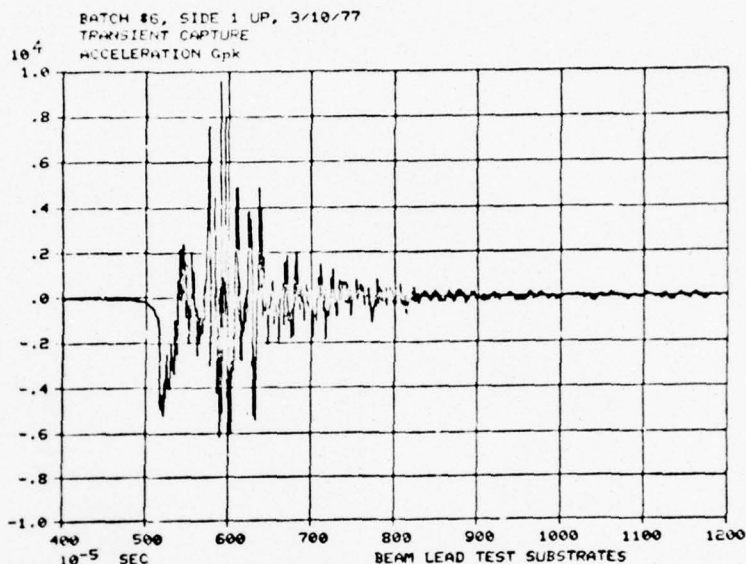


Figure 5.1.5-2 ACCELERATION
VS. TIME GRAPH

5.2 GLOBAL PULL TEST

The global pull test specific in MIL-STD-883, Method 2011, Test Conditions G and H, provides no information about any of the individual bonds, but provides only statistical information about the sum of the bonds. Nevertheless, global pull tests were performed on this program in order to gather data that can be compared on a one-to-one basis with traditional pull test data.

5.2.1 Set-Up

Traditionally, this test has been conducted with set-ups of the principle outlined in Figure 5.2.1-1. A heatable wire loop softens a blob of polyvinyl acetate, like Crystalbond 509, and the liquified blob is made to wet the upper surface of a beam-leaded chip. Once the acetate has solidified, the wire loop can be pulled (and the chip with it). It is attached by a pull rod to a vertical displacement set-up with force-measuring sensor.

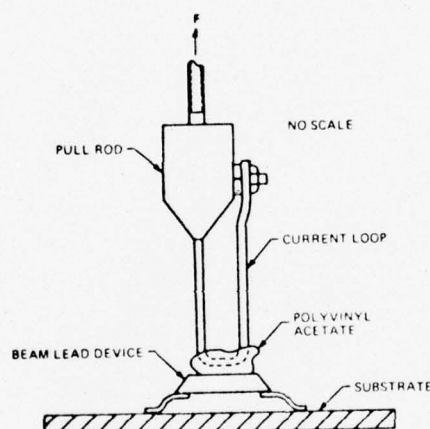


Figure 5.2.1-1 GLOBAL PULL TEST SET-UP

We have created a similar set-up where, instead of the wire loop, we would heat up a little hook and glue it onto the chip with the polyvinyl acetate, then pull it afterwards (on another machine). But we found this method as desperately slow as the wireloop method. Furthermore, the adhesion of the Crystalbond 509 leaves something to be desired. Often, the loop or the hook pulls away from the chip.

5.2.2 Our Method

A much more practical method was found to be the gluing of a loop or a hook permanently on each chip destined to be pulled.

The cement to be used had to be much stronger than vinyl acetate. It had to be viscous enough to stay on top of the chip and not creep underneath. We found the epoxy Ablestik 293-1 to fill the bill.

Whatever the method used, the hook or loop has to be adapted in size to the chip to be pulled. On our substrates, chips of four (4) different sizes are mounted. Here are the solutions adopted:

For the smallest chips (20 x 20 mils), a soft aluminum wire, 5 mils in diameter, was wound around a steel mandrel 10 mils in diameter. The resulting coil was cut into loops of a little more than one turn each. These loops were glued onto the chips with Ablestik 293-1 (epoxy) as shown in Figure 5.2.2-1.

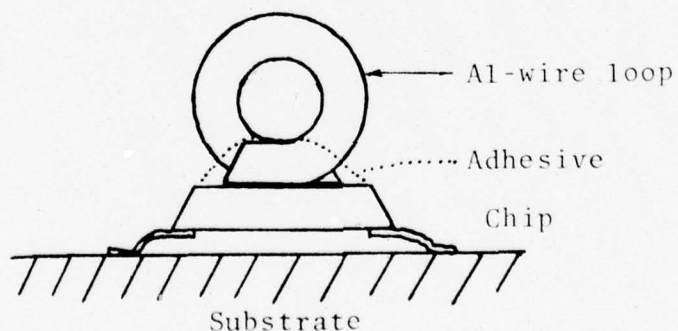


Figure 5.2.2-1

For the 16-beam chips, which measure 40 x 40 mils, we shaped kovar "nails" (the nail-head is 40 mils diameter) into hooks and glued them on the chips directly with the same adhesive (Ablestik 293-1).

5.2.2 (Cont.) Our Method

For the larger chips (85 x 95 mils, 33 beams, and 105 x 115 mils, 42 beams), previous experience had taught us that a 40-mil diameter hook pulling on center would often break the chip without pulling the beams. We therefore manufactured (by photoetching) brass chips 80 mils x 90 mils x 10 mils, which we soldered to the nailhead of the hooks. The hooks with the brass chips were then glued onto the beam-led chips, as shown on Figure 5.2.2-2.

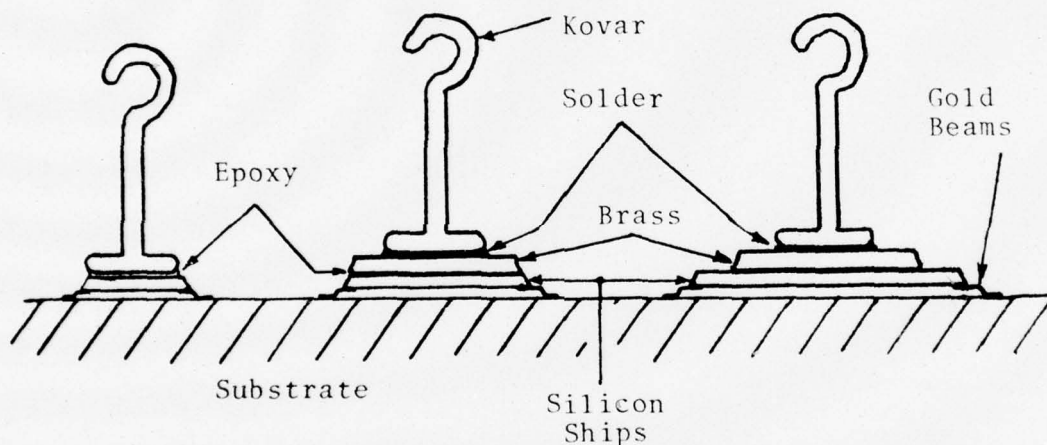


Figure 5.2.2-2

For all the chips with hooks, the pulling instrument was an Instron pull-tester. The most sensitive scale of the load cell was used, which applied to an amplifier/recorder system, gave us a 500 g force full scale (or approximately 5 Newton). For the small chips (with loops), the pulling instrument was a modification of our push tester (see Chapter 6), as shown in Figure 5.2.2-3.

5.2.2 (Cont.) Our Method

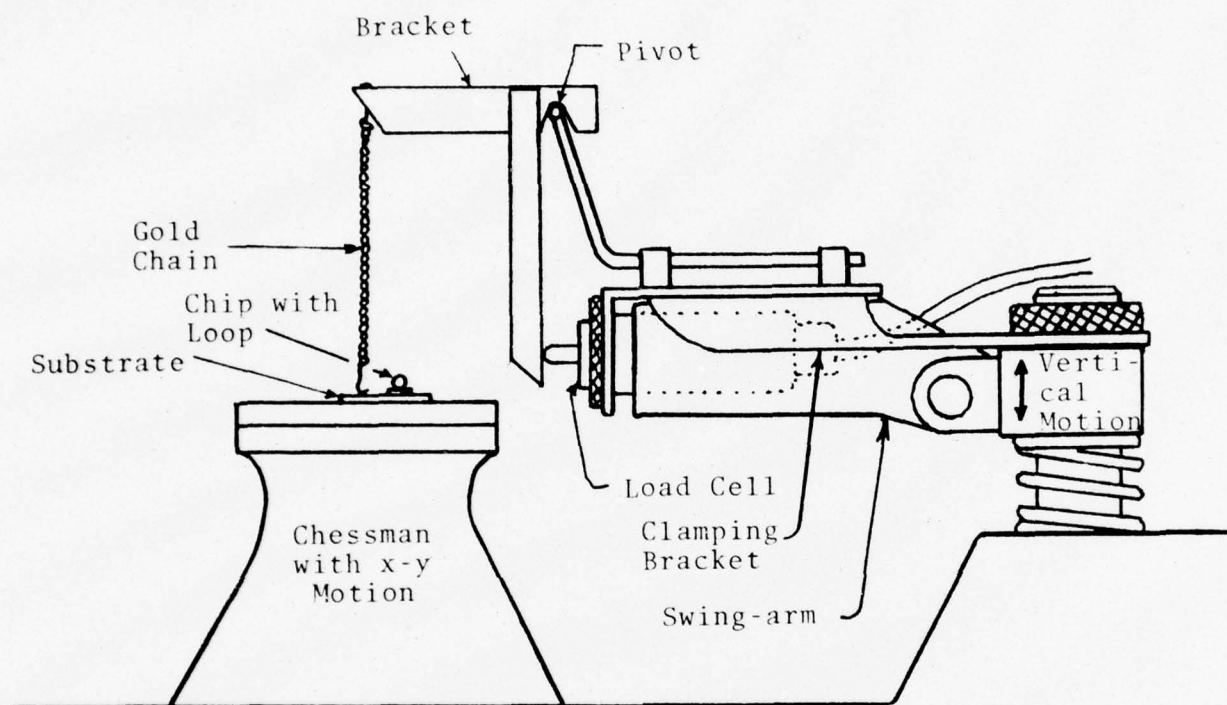


Figure 5.2.2-3

5.3 CONCLUSIONS

The main information gained by the destructive pull test is in terms of what types of failures occurred. Here are, on Figure 5.3-1, the various types of failures.

5.3 (Cont.) CONCLUSIONS

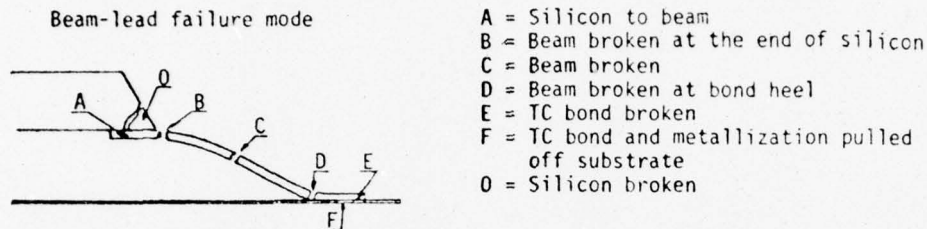


Figure 5.3-1 FAILURE MODES

The only true bond failure is failure type E. In Figure 5.3-2, we have plotted the percentage of type E failures after destructive pull test for three typical configurations of substrates. This statistic makes one fact appear clearly: TC bonding of beam-leaded chips on thick film just does not give the weld-like bond obtained on pure thin-film gold. However, abrasion of the thick film surface just before bonding improves the quality of the bond.⁴¹

To expand on the facts leading to these conclusions, we have synthesized the results of our extensive study on Figure 5.3-3. This graph shows the results of the push tests⁴² INDEPT performed on large samples of each batch of test substrates as they underwent environmental testing.

⁴¹ Point C in Figure 5.3-2 could have been lower if a more consistent abrasion method had been used.

⁴² INDEPT at a force level of 15 grams.

5.3 (Cont.) CONCLUSIONS

On Figure 5.3-3, the ordinate represents the percentage of good bonds observed at INDEPT^{L1}, while the abscissa locates the various types and sub-types of substrates.

One can see that monolayer thick-film substrates printed with fritless gold paste (Type 1) or low-frit gold paste (Type 2 and 4) can lead to a bonding reliability comparable to thin film. The high-frit gold (Type 3) is not so good. As to the multilayer substrates, they lead to increasingly worse bonding reliability as their complexity increases, if nothing is done to their surface. For substrate Type 8 and 9 with untreated surface, there were 100% failures even before the first test (points not plotted on Figure 5.3-3).

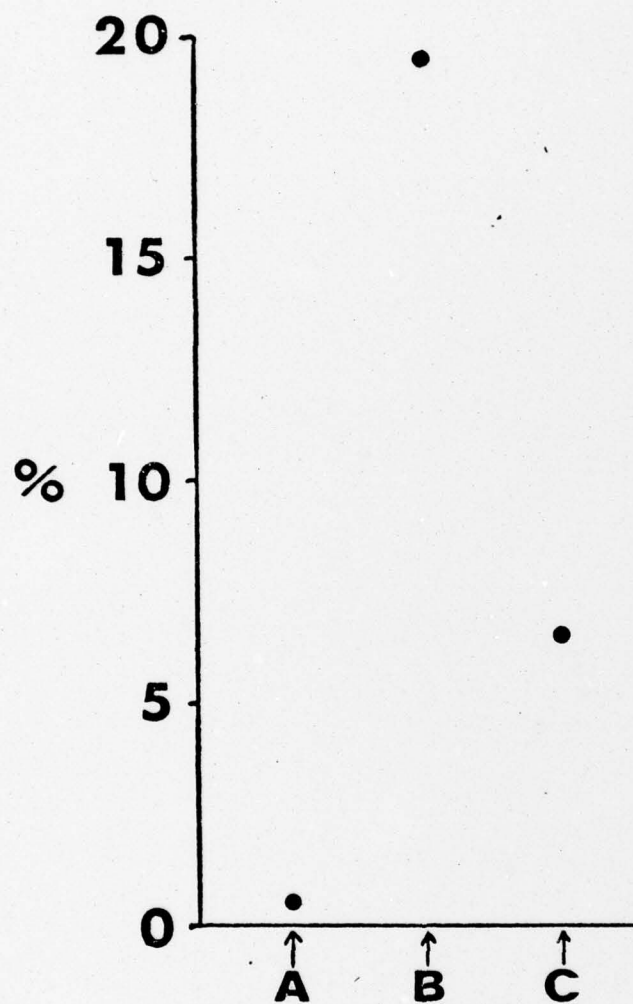
The bonding reliability becomes drastically better if the thick film substrate is abraded^{L2} just before bonding. Substrates Type 8 and 9 were treated that way and displayed a better bonding reliability than any other multilayer thick film substrate. The failures observed were so few that no influence of the lines underneath the top layer could be observed.

We recommend, therefore, to abrade the surface of any thick film circuit where bonding of beam-leaded chips is to be done. There seems to be no problem in running lines underneath the bonding pattern, as long as the waviness created is less than the thickness of a beam.

^{L1} INDEPT at a force level of 15 grams.

^{L2} We did it with a fine fiberglass brush, but other means (e.g., gentle sandblasting) are certainly possible.

5.3 (Cont.) CONCLUSIONS



A = THIN FILM
B = MONOLAYER THICK FILM (UNTREATED)
C = THICK FILM (ABRADED BEFORE BONDING)

Figure 5.3-2 BOND FAILURES AFTER DESTRUCTIVE PULL TEST

5.3 (Cont.) CONCLUSIONS

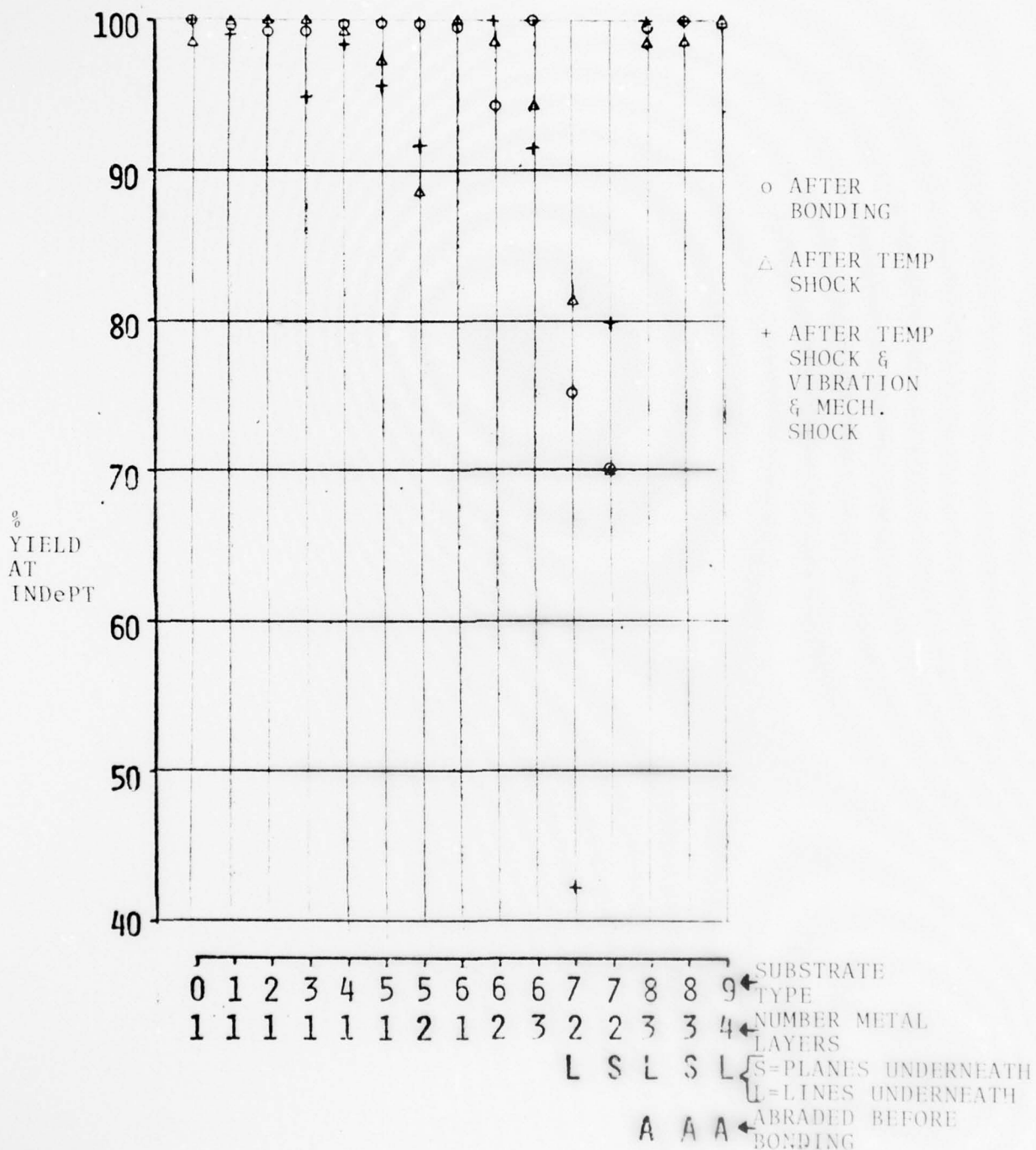


Figure 5.3-3 YIELD THROUGH ENVIRONMENTAL TESTING FOR VARIOUS SUBSTRATES

SECTION 6

BOND TESTING (INDIVIDUAL BEAMS)

The fabrication of high reliability hybrids using beam-leaded chips needs a non-destructive method for bond testing, since destructive testing of sample bonds gives only statistical probability information.

At the beginning of this program, there was no commonly accepted method of performing non-destructive bond testing of beam-leaded chips. This contract asked us to explore methods of doing non-destructive bond testing of beam-leaded chips.

6.1 ALTERNATIVE CONCEPTS FOR INDIVIDUAL BEAM PUSH TESTING

The first attempt was to miniaturize the global pull test (described in MIL-STD-883, Method 2011 and adapt it to single beam pulling, as explained in Figure 6.1-1. This method proved unsuccessful. The very small bonded surface of a beam less than 10^{-5} in.² ($.0065 \text{ mm}^2$) just does not allow sufficient surface area for the adhesive. Also the adhesive material, when softened, could not be contained within this small area. It spread to adjacent beams.

The second method (push testing of individual bonds) gave us, at the outset, enough hope to justify putting an important part of the resources of this program into its development.

Let us first state the problem of individually push testing bonded beams. A beam is a plated gold ribbon of about 0.5 mil (.013 mm) thickness before bonding. After bonding, depending upon the bonding force and the hardness of the substrate mounting pad, the bonded ribbon protrudes by 0.4 mil (.01 mm) or less

6.1 (Cont.) ALTERNATIVE CONCEPTS FOR INDIVIDUAL BEAM PUSH TESTING

(down to zero) above the surface of the mounting pad. In order to push the bonded portion of such a beam, one has to "catch" the edge of the beam which is 0.2 (.005 mm) to 0.4 mil (.01 mm) high. This requires a very sharp tool. However a sharp tool might dig into the gold.

6.2 SUCCESSFUL INDIVIDUAL BEAM PUSH TEST FIXTURE

After extensive experimentation, we settled on the configuration shown in Figure 6.2-1. A tool of very hard material is shaped to a very sharp edge (R typically is 1 to 2 microinches (.025 to .05 μ m). In order to catch the edge of the beam, we have found the optimum angle α to be about 25° . To avoid digging into the gold, angle δ should be approximately 5° . $\delta = 0$ will cause the tool to slide over the edge of the beam.
beam.

The material of the tool has to be very hard in order to keep its sharp edge. A stainless steel tool was tried first. It lasted for about four tests. Its sharp edge became too dull to catch the edge of the beam. A stellite steel tool lasted for about 50 tests. Sapphire was found to last for several thousands of tests between sharpenings. It is relatively easy to re-sharpen. The materials used were sapphire record engraving tools. Their original shape is shown on Figure 6.2-2. The original shape was ground and polished to several different configurations, none of which was satisfactory.

6.2 (Cont.) SUCCESSFUL INDIVIDUAL BEAM PUSH TEST FIXTURE

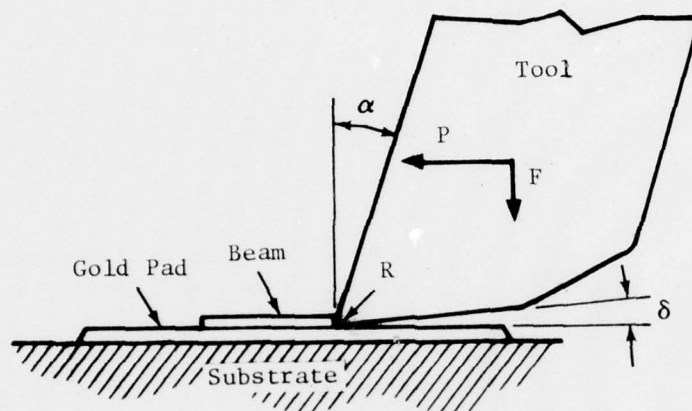


Figure 6.2-1 BEAM PUSH TEST CONFIGURATION

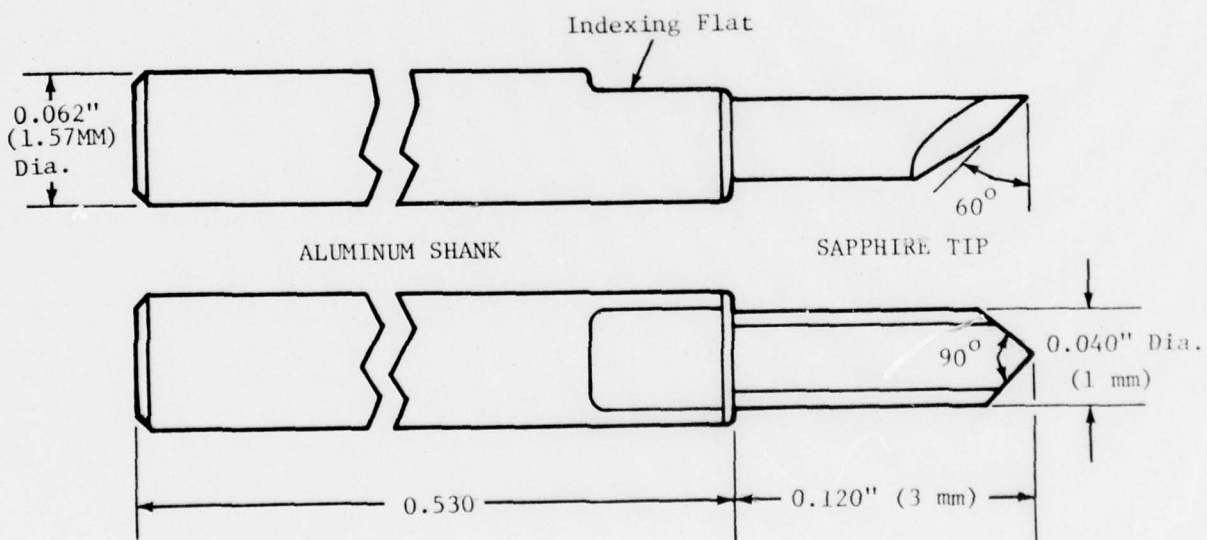


Figure 6.2-2 ORIGINAL SHAPE OF SAPPHIRE ENGRAVING TOOLS

6.2 (Cont.) SUCCESSFUL INDIVIDUAL BEAM PUSH TEST FIXTURE

The final, successful configuration is as shown in Figure 6.2-3.

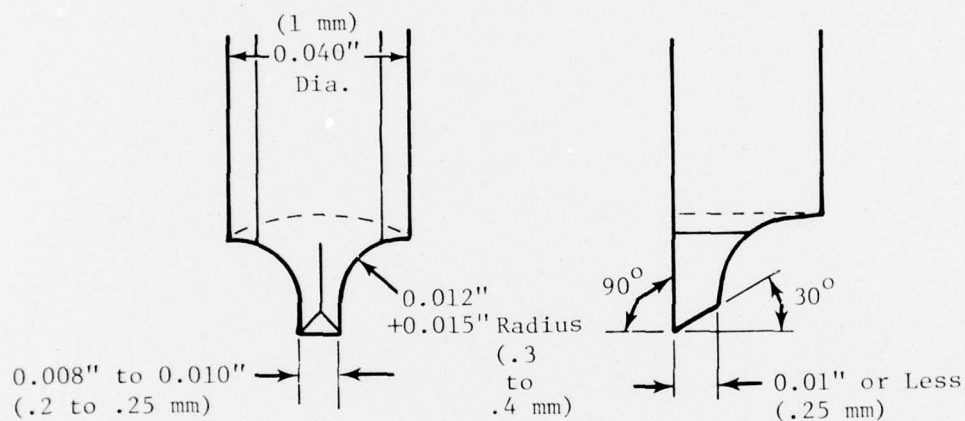


Figure 6.2-3 SUCCESSFUL TIP CONFIGURATION

The shaft of the sapphire tip was mounted to an arm that holds it at 25° (angle α in Figure 6.2-1). Figure 6.2-4 shows this assembly.

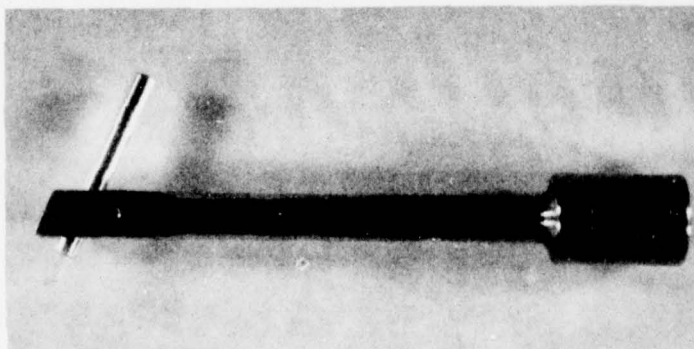


Figure 6.2-4 SAPPHERE TIP MOUNTED ON ARM

6.2 (Cont.) SUCCESSFUL INDIVIDUAL BEAM PUSH TEST FIXTURE

Besides the proper shape and angles of the tool, an important factor in preventing the tool from "digging in" is that the vertical force (F in Figure 6.2-1) be limited to less than 2 grams. The horizontal push force (P) is the test force that must be measured.

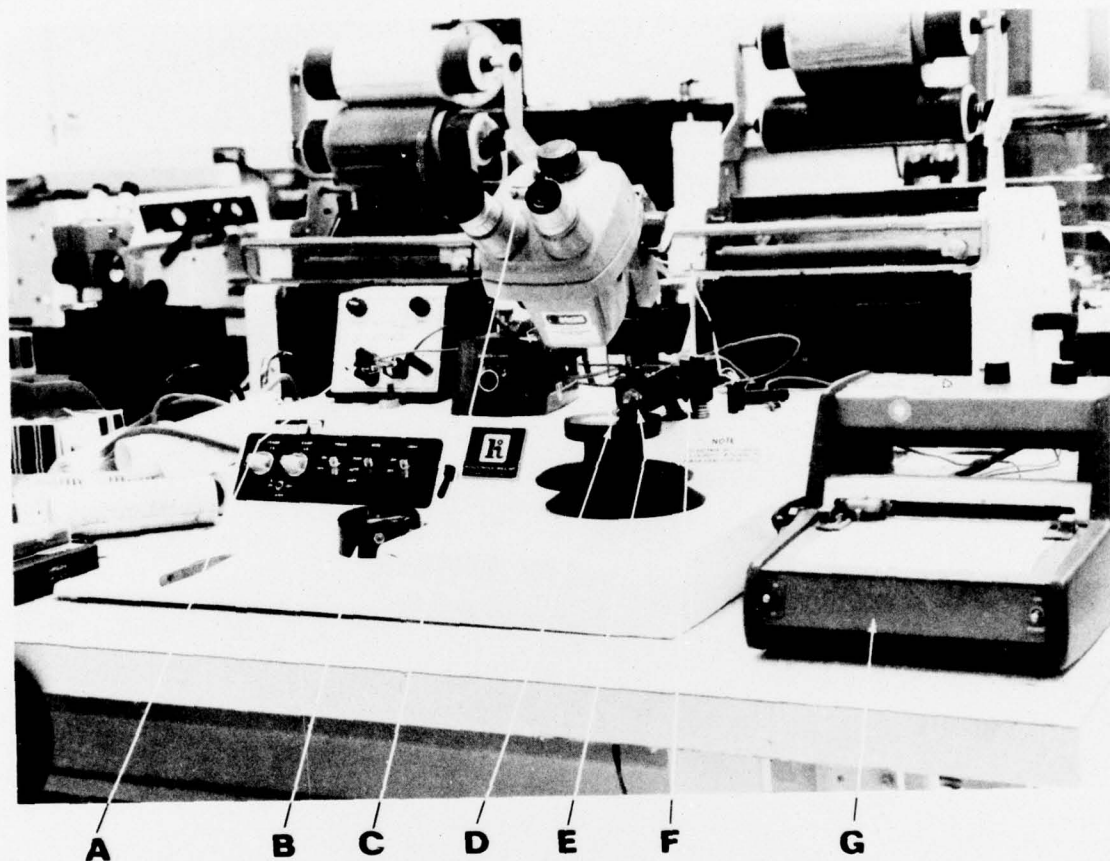
The assembly of tip and arm (shown in Figure 6.2-4) is mounted on the shaft of a force sensor (Statham UC3 load cell). The force sensor chosen was selected because of its sensitivity, linearity and small displacement. This last factor is important if the push test is to be truly non-destructive. With the load cell built into this instrument, if a failure occurs with a 15 g push, the motion of the tool is only about 2 mils (= .050 mm). This generally does not damage the beam, which can be bent back in place and re-bonded. The load cell is mounted on a frame and is counter balanced so that while the sapphire tip is free to move in the vertical direction, the maximum force "F" will be less than 2 grams.

The output of the load cell is amplified, then fed into a strip chart recorder. An adjustable level discriminator circuit was installed. This circuit, after being calibrated, turns on a light when the desired push force is reached.

A Hugle ultrasonic wire bonder was modified to accept the above described fixture in place of the bonding head. The capability for pantograph manipulation of the substrate was **retained**; thus providing for excellent x, y and rotary positioning **of the bonded beams**. The switch actuated motor drive was also **retained** in order to provide for controlled vertical movement of the sapphire tip.

The following are photographs of the completed fixture.

6.2 (Cont.) SUCCESSFUL INDIVIDUAL BEAM PUSH TEST FIXTURE



- | | |
|-----------------------------|--------------------------|
| A: Amplifier for load cell. | E: Load cell. |
| B: Motion control lever. | F: Horizontal pivot. |
| C: Warning light. | G: Strip-Chart Recorder. |
| D: Push tool. | |

Figure 6.2-5 COMPLETE INDEPT SET-UP

6.2 (Cont.) SUCCESSFUL INDIVIDUAL BEAM PUSH TEST FIXTURE

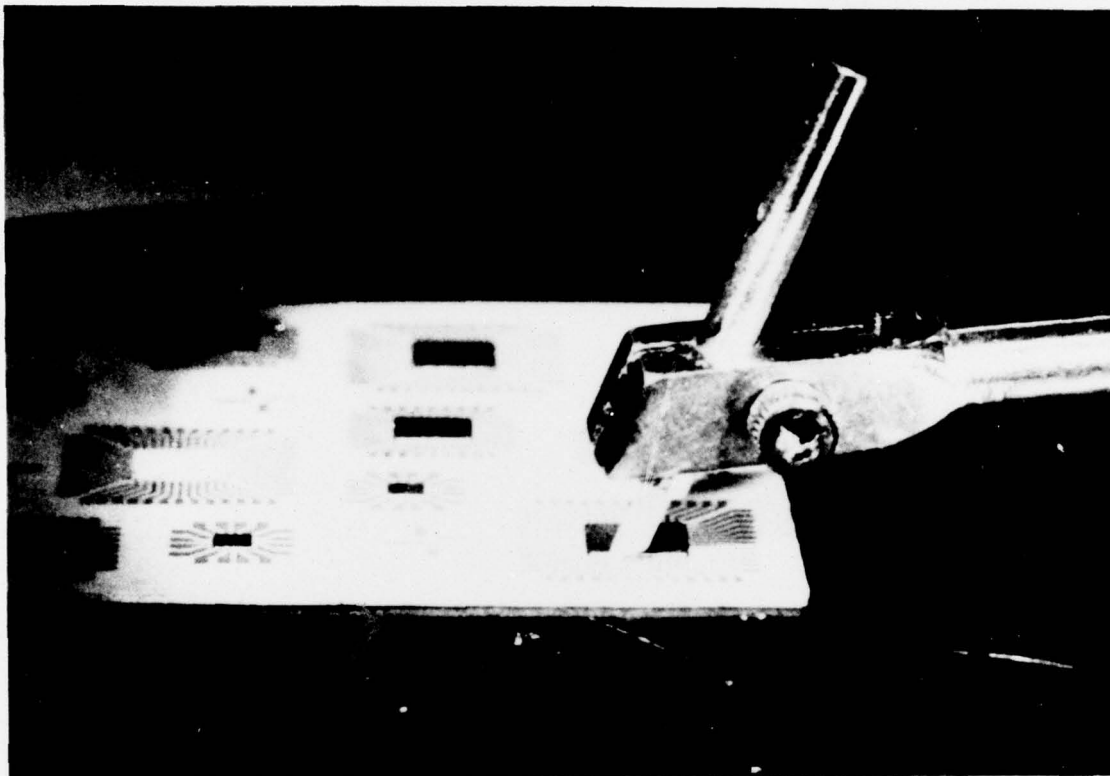


Figure 6.2-6 INDEPT SET-UP DETAIL

6.3 INDEPT ON THIN FILM SUBSTRATES

Chips mounted on thin film substrates usually present the easiest case for push testing. The thin film gold, built up by plating, is very compact and rather hard. So, upon bonding, the beams don't embed themselves in the gold of the pads. Visually, even for squashout factors of two (2) or more, the edges of the beam are quite distinct and sharp. And with a squashout factor of 1.1 to 1.6, the beam presents a good edge for INDEPT pushing from the end (Figure 6.3-1) which is the preferred direction.

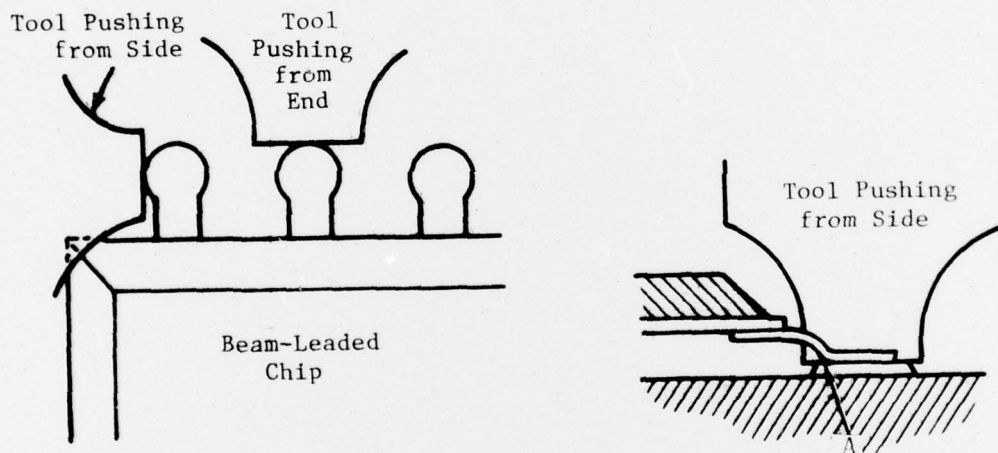


Figure 6.3-1 TOOL PUSH POSITIONS

If the end of the bond is not accessible, the bond can be pushed from the side. However, pushing from the side requires additional caution.

6.4 INDEPT ON THICK FILM MONOLAYER SUBSTRATES

The chips mounted on thick film substrates can be more difficult for INDEPT unless the design of the circuit layout takes the push test into account. The thick film gold, after firing, is thicker, softer and much more porous than the thin film gold. The beams, upon bonding, can become embedded in the thick film gold to the point where it is extremely difficult to see where the beam ends. The end of the beam is usually embedded. Therefore, push testing from the side is the only way for chips mounted on thick film. If the pad is much wider than the beam, we have the situation shown in Figure 6.4-1, where no push test is possible.

If the pad is a narrow line (which it must be for a chip of more than four (4) beams) not much wider than the beam, then it assumes a semicylindrical cross-section after firing (Figure 6.4-2). After bonding, at least one of the edges of the beam will slightly protrude and be accessible for pushing from the side.

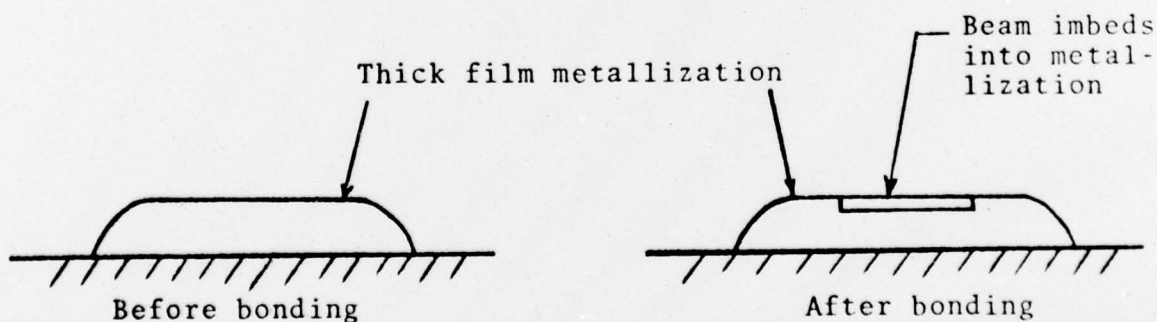


Figure 6.4-1 CROSS-SECTION VIEW OF WIDE THICK FILM BONDING PAD

6.4 (Cont.) INDEPT ON THICK FILM MONOLAYER SUBSTRATES

Thick film metallization.
Note semicylindrical shape

Beams are typically imbedded
on only one side

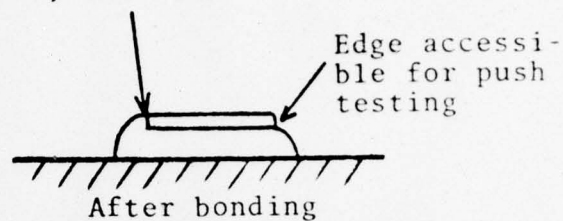
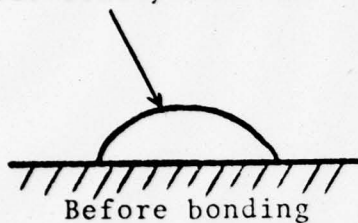


Figure 6.4-2 CROSS-SECTION VIEW OF STANDARD-WIDTH THICK FILM MOUNTING PAD

6.5 INDEPT ON MULTI-LAYER THICK FILM SUBSTRATES

What was said of the push testing of the beams on monolayer thick film applies to multilayer also. In no case did we find the waviness of the top surface to interfere with the side push test.

6.6 INDEPT FORCE DETERMINATION

In the destructive pull test, the most stringent criterion for good bond is that the bonded portion of the beam must remain attached to the substrate when the chip is pulled away. Such a criterion insures that the bond to the substrate is not the weakest link in the chain of possible failure points. We attempted to determine a force level that would correlate our individual-beam push techniques to this most stringent criteria in the destructive global pull test. The concept followed was that if we could know the INDEPT force level of the bonds and if we could then show a high correlation between that force level and the stringent criterion, then that force level could be substituted as the criterion for judging the bonds.

6.6 (Cont.) INDEPT FORCE DETERMINATION

We proceeded as follows: We arbitrarily chose 15 grams as the level of our push test. After many attempts, we succeeded in creating bonds on thin film that were marginal at the 15-gram test. The marginal condition was judged by the fact that 50% of the bonds (all made with the same parameters) failed at 15 grams INDEPT. Those that passed the 15 grams were then pulled by the chip until failure. 47% of these beams showed bond failure.

Next we chose 25 grams as the level of push test, and created bonds which were marginal at the 25-gram test. Those that passed the 25-gram test were then pulled to failure. 12.5% displayed bond failure. Figure 6.6-1 is a graph of the percentage of bond failures as a function of the force passed at INDEPT. A simplistic extrapolation seems to indicate that an INDEPT with a force of 30 grams would insure a high correlation with the destructive pull test. However, the practical experience we have gathered told us that 30 grams is too high a force for a truly non-destructive pull test. Even 25 grams push did permanent damage to some beams (even though the beams did not fail).

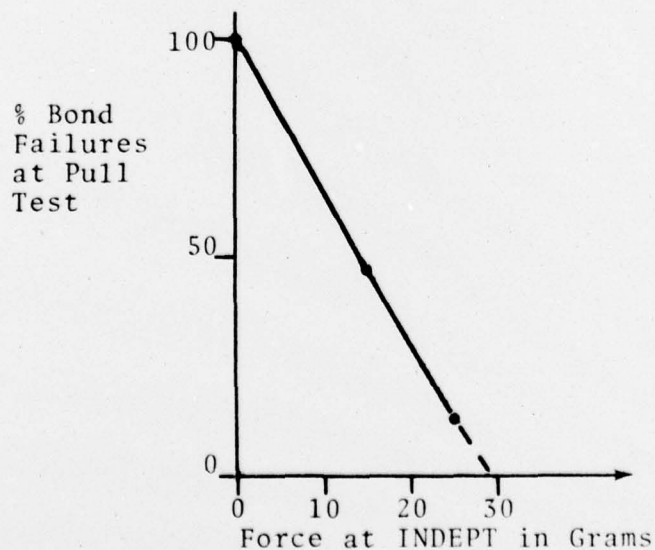


Figure 6.6-1

6.7 CONCLUSIONS

Over 5,000 beams were tested during this program at a 15-gram INDEPT force level. It was seen that this level was adequate for detecting the weak bonds, without damaging the good ones. The test criteria mentioned under 6.5, which says that the bond should not be the weakest link of the connection, is arbitrary. But if we look at MIL-STD-883, Method 2011.1, Conditions G and H, we see that the bonds do not have to remain after destructive pull test, but only have to satisfy a minimum force requirement of 30 grams per millimeter of total width of the beam. This translates into 2.3-gram force for every standard 3-mil-wide beam.

INDEPT can be more directly related to the test criteria applied to Flip Chips: MIL-STD-883A, Method 2011.1, Condition E. There, a shear force is applied and has to be at least 5 grams per bump at rupture. The arbitrary 15-gram INDEPT is more stringent.

If a failure occurs at INDEPT, the displacement of the tool at 15-gram force is so small (~ 2 mils = 0.05 mm) that the beam can be pushed back in place without damage and can be re-bonded. Because it is non-destructive, it can be applied to the deliverable units instead of only to sample lots. Therefore, it goes further than the MIL-STD tests to insure reliability of the deliverable hybrids.

6.8 SUGGESTIONS FOR FURTHER DEVELOPMENTS

The work performed during this program indicates that INDEPT is a viable way of testing the bonds of Beam-Leaded Chips. It is still crude, however, and efforts should be spent to improve it

6.8 (Cont.) SUGGESTIONS FOR FURTHER DEVELOPMENTS

in the following directions:

- A) Continue the work outlined under 6.5 and improve the feasibility of INDEPT at forces greater than 15 grams.
- B) Improve the "machinery" and develop a precise and non-human dependent force limitation device.
- C) Expand the scope of INDEPT to be applicable to tape-carrier mounted chips (outside and inside bonds) and flying wire bonds.

It must be noted that, while an ordinary wire-bond pull test stresses both* bonds of a wirebond connection, INDEPT stresses each bond individually, and would not stress the wire or beam.

* not necessarily with the same force

SECTION 7 DESIGN GUIDELINES

Design guidelines for beam-leaded chips on thin and thick film substrates are covered in Volume II of this report, Section 7.6.4.

A few special design rules are to be added, however, if one intends to perform on the bonded chips a non-destructive push test (INDEPT) like described under Section 6 (Volume II).

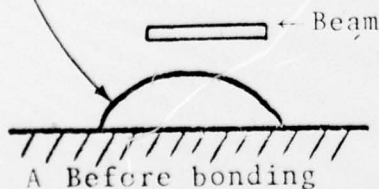
If the substrate metallization is thin film, no special layout precaution is needed, because the beam does not embed itself in the metal pad.

7.1 DESIGN RULES WITH THICK FILM SUBSTRATES

if the metallization is thick film, one should observe the following rules:

- 1) The conductor pads where the beams are to be bonded should not be much wider than the beam (pad width maximum 5 mils (0.125 mm) if beam is 3 to 3.5 mils wide (.075 to .09 mm)). Figure 7.1-1 explains it.

Thick film metallization.
Note semicylindrical shape



Beams are typically imbedded on only one side

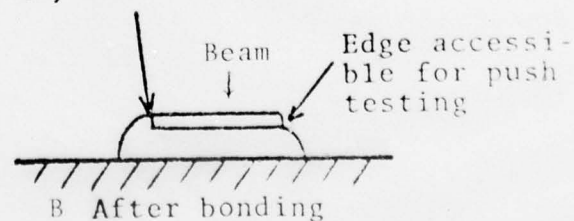


Figure 7.1-1 BEAM WIDTH REQUIREMENT FOR PUSH TEST ACCESSIBILITY

7.1 (Cont.) DESIGN RULES WITH THICK FILM SUBSTRATES

- 1) A narrow thick-film pad takes, after firing, a semi-cylindrical cross-section, like under A (Figure 7.1-1). Thick film being porous and spongy, it takes, after bonding, the shape sketched under B. If the pad is narrow enough, one (or both) edge of the beam will be accessible for push-testing.
- 2) The configuration of the thick film pads around a chip has to take in account the tool used to perform the push test. This is explained in Figure 7.2.2. In A: no push test is possible, because the tool is wider than the length of the pad portion comprised between the heel of the beam and the first bend of the pad. The tool will rest on the shoulder S of the pad bend.

In case B, the straight portion of the pad is longer than the push tool is wide, and a push test is possible.

Therefore: the portion of the pad extending straight from the chip should be longer (from the heel of the beam) than the push tool (for INDEPT) is wide.

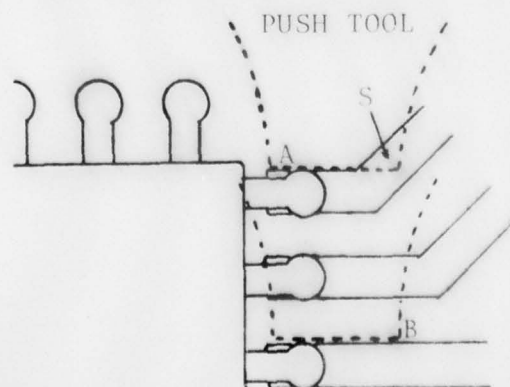


Figure 7.2-2 CONDUCTOR CONFIGURATION ON SUBSTRATES

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